FLUORSPAR DEPOSITS OF KENTUCKY

LOUIS WADE CURRIER

Kentucky Geological Survey

WILLARD ROUSE JILLSON
DIRECTOR AND STATE GEOLOGIST

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1923

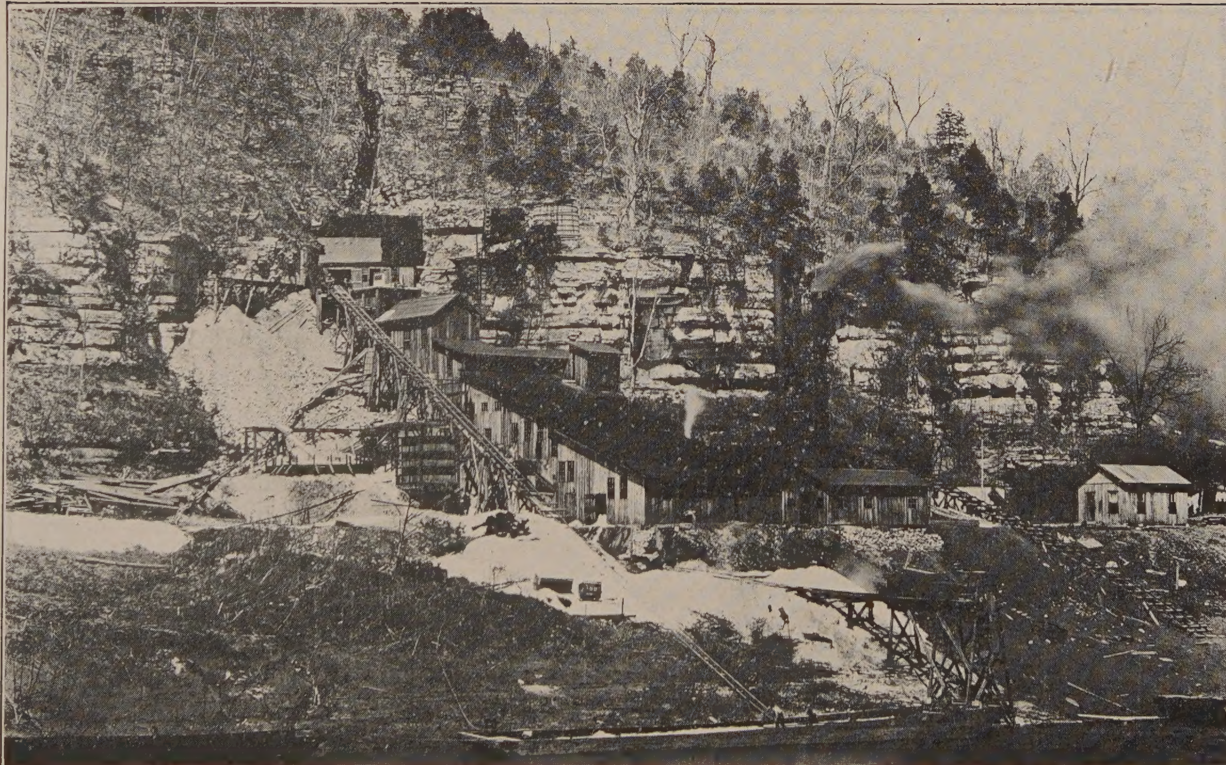

PHOTO BY W. R. JILLSON

Twin Chimney flourspar mine, Mercer County, Kentucky River gorge.

Fluorspar Deposits of Kentucky

A description and interpretation of the geologic occurrence and industrial importance of Kentucky Fluorspar

BY

Louis Wade Currier
ASSISTANT GEOLOGIST

*Illustrated with 43 Photographs
Maps and Diagrams*

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Letter of Transmittal

Syracuse, New York, June 1, 1923.

DR. W. R. JILLSON,
Director and State Geologist,
Kentucky Geological Survey,
Frankfort, Kentucky.

Dear Sir:

Allow me to transmit herewith my report on the Fluorspar Deposits of Kentucky, with illustrations. The field work for this report has extended over parts of three summers, 1920, 1921 and 1922. While this work was practically completed in 1921, the radical change in fluorspar industrial conditions which followed, and certain field developments made it advisable to go into the western field again in 1922.

It has been my aim to present a broad, general treatment of the subject rather than one of great detail, a mode of treatment made necessary in part by the lack of topographic base maps of the greater part of the field. The work has demonstrated the great future importance of the western Kentucky field to the fluorspar industry of the country.

It is hoped that the report will present facts and interpretations valuable to operators, prospectors, consumers. scientists and such others as have interest in the industry.

Very truly yours,

LOUIS W. CURRIER,
Assistant Geologist.

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Preface

Dependent upon certain large staple industries, and essential to them, the fluorspar industry occupies a favorable economic position. Its growth since its inception in this country has been consistent with these facts. With the greatly expanded industrial activity of the past three decades and the seemingly limited nature of our flourspar resources, it is indeed important that the fluorspar industry should receive critical attention to the ends that conservation and efficient utilization of known deposits be effected, and extent of resources be ascertained. Occupying, as it does, an important economic position, it becomes a national duty to encourage and assist the Kentucky industry, a duty which devolves in part upon the Commonwealth, and in part upon the nation.

The excellent and highly valuable work of the United States Geological Survey prepared nearly two decades ago has, because of changing conditions and greater development, become inadequate to meet the greater needs. Accordingly, the Commonwealth of Kentucky, through its own Geological Survey, is attempting to furnish necessary information regarding its own resources. That this has been partly accomplished already is manifest through the recent publications of the work of Dr. Stuart Weller, on the Stratigraphy and structure of parts of western Kentucky. Supplementing this work, the present volume attempts to interpret conditions, and to offer practical hypotheses and suggestions. It is not, however, the writer's intention to do other than describe and interpret the general features of the Kentucky deposits and the market conditions. It becomes, therefore, a statement of opinions.

It was not possible to visit and examine all prospects and mines. Wherever possible mines were entered, but in numerous instances the writer was dependent upon statements concerning underground conditions. Literature has been freely drawn upon.

The stratigraphy of the districts has been limited to that amount necessary to an understanding of matters pertaining to origin of the deposits. The writer is here indebted in a large measure to the work of Dr. Stuart Weller. The igneous rocks have been described in greater detail as a matter of scientific record and reference. The justification of a somewhat lengthy treatment of origin and paragenesis of the veins lies in the proven practical importance of genetic hypotheses generally as leading to conclusions regarding persistence of deposits. The chapter on development is designed to indicate the extent to which prospecting and mining have been carried on.

Louis W. Currier,
Assistant Geologist.

CHAPTER I.

INTRODUCTION

The production of fluorspar constitutes a very important mineral industry in Kentucky. The mineral is extensively used in certain chemical and metallurgical plants, and is the only naturally occurring mineral known that can be utilized for the purposes to which it is applied. Few localities appear to be provided with resources of this substance on such a scale that they may compete with the fluorspar mining industry in Illinois and Kentucky. The latter State finds a very strong competitor in the Illinois field, not because of any superiority of the latter in quality or quantity of the mineral available, but because of the more concentrated development that has been carried on there. Thus it would appear that the industry has great promise in Kentucky if properly developed and encouraged.

Fluorspar is mined in two districts in the Commonwealth of Kentucky, known as the Western Kentucky and the Central Kentucky fields. The former far outweighs the latter in importance. The possibilities of the latter field are not, however, fully known, as there has been very little study made of the veins in that district, in which also very limited development has been undertaken. In western Kentucky, the mineral has been produced from shallow mines for several decades, and the production from this district has comprised practically the entire Kentucky output of fluorspar.

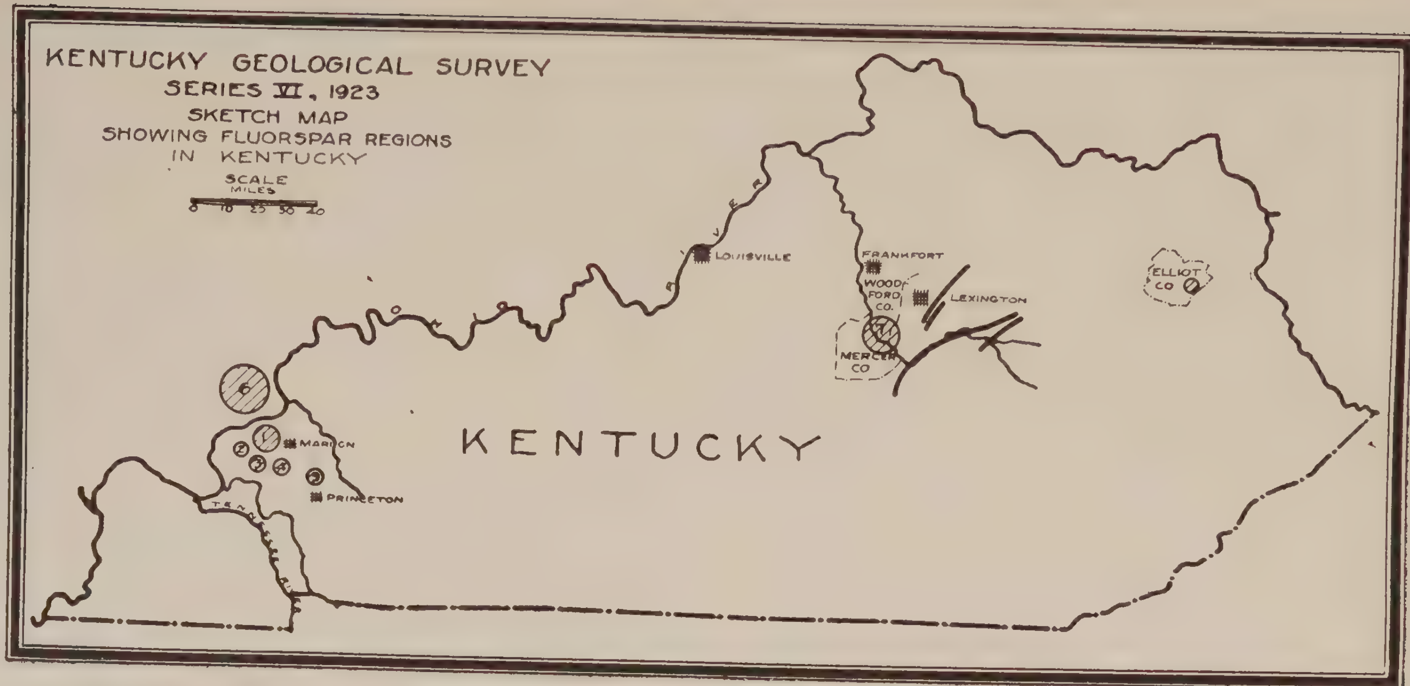
The field and laboratory studies which form the basis of this report were carried on during parts of the summers of 1920 and 1921. The field was also briefly visited in July, 1922. The investigation has consisted of a study of the geologic structure of the deposits as disclosed in mines and prospects. No attempt has been made to map the deposits or the other geologic features of the regions, inasmuch as such detailed work is now being done by Dr. Stuart Weller. It is rather the object of this paper to describe and discuss the characteristics of the deposits themselves, and the bearing of these features on the successful exploitation of the veins.

The writer is greatly indebted to the various mine operators for their generous and helpful cooperation in the field. Especially should be acknowledged the assistance of Mr. A. H. Reed, mining engineer at Marion and owner of the Big Four mine, who has given freely the use of maps and photographs, and has also given the writer much information acquired through years of experience. Mr. Shelby, field manager of the Kentucky Fluorspar Company, the officials of the Holly Ore & Mining Company, and numerous other operators have been most generous in allowing and facilitating access to mines and prospects. In but two instances, indeed, has the writer met with a disinclination on the part of a mine owner to allow underground examination. Practically all of the work has been carried on in the western field. It has not been possible to make a close study of the deposits in the central part of the State, and accordingly only a brief description will be given of this district. (Chapter IX.) Chapters I to VIII inclusive deal entirely with the western district.

Geography and History

The fluorspar mining district of western Kentucky embraces the greater part of Crittenden, Livingston, and Caldwell Counties. Lyon and Trigg Counties have no developed mines, though the presence of fluorspar is to be noted in a few scattered prospects. The major part of the mining development has taken place in Crittenden County. The eastern portion of Livingston County, and the northwestern portion of Caldwell County have important developments, containing several mines and meritorious prospects. In the remaining portions of the district only small and scattered prospects are known, and there is little surface indication that promising veins are existent in these places.

Geographically, the western field is limited on the north and west by the Ohio River. Just across this stream is the important Illinois fluorspar district, from which the greater part of the United States production of the mineral has come. The two largest and deepest fluorspar mines of the country are situated near the Illinois shore of the Ohio, and the faults containing these deposits apparently run across the river into Kentucky.



(1) Key map of Kentucky showing geographic positions of fluorspar fields. Circles (except in Elliott Co.) indicate districts, and apparent centers of greatest mineralization. Areas of circles do not indicate extent of districts exactly, as in the western field the districts merge into each other.

1. Marion-Sheridan district; 2. Lola district; 3. Salem district; 4. Mexico-Claylick district; 5. Fredonia-Princeton district; 6. Illinois fluorspar field; 7. Central Kentucky fluorspar field. The Kentucky River fault zone and the West Hickman fault zone are shown southeast of Lexington. The Elliott County igneous area is indicated.

From a geologic study it becomes apparent that the Illinois and adjoining Kentucky fields are both parts of a single distinctive province, and that the same structural and mineralogic features are, in general, common to both. The Illinois field has already been studied by the writer,[1] and while the subject matter of this paper is concerned with the Kentucky district it will be necessary to refer occasionally to the Illinois deposits, especially in connection with the discussion as to the origin of the fluorspar.

The key map, Fig. 1, indicates the geographic position of the district.

Previous Geologic Work

About the middle of the last century D. D. Owen reported the occurrence of fluorspar veins of considerable size in western Kentucky, and his observations are recorded in the State publications of the time. In 1875, Charles J. Norwood recognized "that the Kentucky deposits occur in true veins associated with deep faults," and in 1878 he published a report of his reconnaissance of the lead district of Crittenden, Livingston, and Caldwell Counties.[2] At this time, and previously, mining was carried on practically only for lead, which in the form of galena occurs generally in the fluorspar veins. In the early '70s, however, a market for fluorspar developed, and since that period production of the mineral has been continuous.

In 1893 the late Mr. S. F. Emmons, eminent geologist of the United States Geological Survey, published a description of the Illinois district,[3] and in 1903 H. Foster Bain examined the Illinois district under the auspices of the United States Geological Survey. Results of his investigation appeared in 1905.[4] These two publications deal almost entirely with the Illinois deposits, but some references of interest are made to the Kentucky side, especially in Bain's report.

The chief general work is that of Dr. E. O. Ulrich, who began an investigation for the Geological Survey of Kentucky in 1888, and later (1903) under the combined auspices of the Federal and Commonwealth of Kentucky Surveys continued

[1] State Geological Survey, Illinois; Bulletin 41, pp. 237-304.
[2] Geological Survey of Kentucky, 2d Series, Vol. 1, 1876.
[3] Trans. Am. Inst. Mining Engineers, Vol. 21, 1893; pp. 31-53.
[4] Bain: Fluorspar Deposits of Southern Illinois; U. S. G. S. Bulletin 255, 1905.

his work with the cooperation of Dr. W. S. Tangier Smith. Their paper[5] describes in detail the geology and structure of the region, Dr. Smith's portion relating solely to the mineral deposits. The report covers the entire fluorspar district in Kentucky.

A report on the fluorspar deposits of Kentucky was written by F. Julius Fohs, and published by the Kentucky Geological Survey in 1907.[6] This report deals especially with the industrial aspects of fluorspar, production, mining, technology, uses, etc., and only slightly with the geological features.

In the summer of 1920, Dr. Stuart Weller mapped the western portion of the district for the Kentucky Geological Survey. The area mapped comprises the Kentucky portion of the Golconda Quadrangle, and lies entirely west of the principal part of the developed field. The eastern boundary of the Golconda Quadrangle is the meridian 88° 15′, or approximately a north-south line just west of Salem; the southern boundary is the latitude 37° 15′, or an east-west line approximately one mile south of Salem. The geology of this area is similar in character to that of the rest of the fluorspar district, so that the descriptions of rock formations that appear in Dr. Weller's report[7] will apply to the entire western field.

In 1921 the Kentucky Geological Survey published its most recent statistics on the production of fluorspar in a brief illustrated paper by Dr. W. R. Jillson.[8] During the summer of 1921 Dr. Weller continued his mapping in the Princeton quadrangle, and his report[9] on this area is now available. The mapping of the Cave-in-Rock quadrangle, which includes the remaining important portion of the fluorspar district, was started in the latter part of the summer of 1922 and continued through 1923.

Conclusions

The fluorspar deposits of western Kentucky are true fissure veins occupying fault zones. Local concentration in joint planes

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[5] Ulrich and Smith; Lead, Zinc, and Fluorspar Deposits of Western Kentucky; U. S. Geol. Surv. Prof. Paper 36, 1905.

[6] F. Julius Fohs: Fluorspar Deposits of Kentucky; Kentucky Geological Survey, Bulletin 9, 1907.

[7] Geology of the Golconda Quadrangle. Stuart Weller, Kentucky Geological Survey, Series VI, Vol. IV, 1921.

[8] Production of Fluorspar in Western Kentucky. Willard Rouse Jillson. Kentucky Geological Survey, Series VI, Vol. II, pp. 159-175, 1921.

[9] Geology of the Princeton Quadrangle. Stuart Weller. Kentucky Geological Survey, Series VI, 1923.

of limestone along which there is no displacement are known, but do not reach economic proportions, and are situated in localities where fault-fissure veins are proximate. The bedding type of deposit in which horizontal tabular masses of fluorspar replace limestone formations, and which are characteristic of the Lead Hill district of the Illinois field, are not known to the writer to occur in the Kentucky field. In all other respects the fluorspar deposits of western Kentucky resemble those of the adjoining Illinois field, the two constituting in reality a single geologic and mineralogic province.

The mineralogic association is coarsely crystalline calcite, fluorspar, argentiferous galena, zinc blende, quartz. The silver content of the galena is too low for primary silver exploitation. Barite is found locally in the residual surface clays at the tops of veins, closely associated in a few instances with the fluorspar. These clays form a mantle over limestone areas and reach in some places to a depth of 200 feet. Barite is never prominent in the perfectly solid vein matter where no decomposition of veins or walls has happened.

The veins of greatest economic value are found in areas of faulting where at least one wall consists of the lower thick Ste. Genevieve-St. Louis limestone formation. Where both walls consisted of sandstone, shale, or the thin Chester limestones, conditions were usually not so favorable for the deposition of economic ore-bodies. Only rarely have valuable ore-bodies been found in such horizons. It is believed that during the process of formation coarsely crystalline calcite at first partly occupied the fault fissure, especially between the thick limestone walls. Into such partially filled fissures fluoriferous solutions circulated, the fluorine, whether elemental or combined, reacting with the calcareous filling and walls to effect a partial replacement of the calcite and limestone by fluorspar. Part of the fluorspar was also deposited as fissure filling without replacement. On the basis of vein structures and textures, and theoretical chemical consideration involving the laws of relative solubilities and concentration, the fact of such replacement is considered tenable. The variability in width and purity and, locally, the development of unusually large ore-bodies is believed to be in part the result of such replacement action. It is thought that such horizons as were chemically susceptible to replacement offer most favorable chances in prospecting. As indicated above, such horizons would be the thick lower limestones, at which more than between any other formations the veins carry calcite.

Lead and zinc ore minerals have some importance as by-products in milling. It is not believed that these minerals will be found in such concentration as to give them chief importance in mining. Locally in fluorspar veins, however, unusual concentrations of these minerals are occasionally encountered. The mining of lead and zinc ores will never reach great importance in the district at least to depths of the order of 1000 to 1200 feet. It cannot yet be predicted with assurance that either of these metals will increase at greater depths; such possibility exists, but is speculative.

The continuance of some fluorspar veins, chiefly along master fault zones, to depths of 1000 to 1500 feet is considered probable. Possibly the veins are limited to positions above the thick Devonian shale which, in Hardin County, Illinois, has been found to lie about 800 feet below the base of the St. Louis limestone. Northeast-southwest trends (from nearly N-S to nearly E-W) are predominant along the more important veins. Veins with other courses are frequently of importance if they are clearly associated with mineralized major faults of northeaserly bearing. Locally in such intersecting or divergent minor faults of a major zone exploitation may be successfully carried on; chiefly, however, in proximity to the major fault.

The amount of displacement along a fault seems to bear no particular relation to degree of mineralization. The Rosiclare fault in Illinois, on which the largest fluorspar mines of the country are situated, has a vertical displacement of 130 to 150 feet, while an unusually long fault of 1300 feet displacement in the Golconda quadrangle, as mapped by Dr. Weller, has shown no indication of economic mineral bodies. Until the projected work in the Cave-in-Rock quadrangle (chiefly Crittenden County) is completed no full statement can be made regarding displacement along the chief veins of the district. In most cases, however, conditions point to only moderate displacements (100 to 500 feet) along them.

While the genesis of the fluorspar deposits cannot yet be definitely stated, the particular structures, localization of the veins, relation to faults, presence of igneous rocks, consideration of possible sources of fluorine, mineral associations, and analogies with other mining regions point strongly to an igneous origin by which the unusual peridotite and lamprophyric intrusions and the fluorspar veins become consanguineous. The veins are not structurally connected with these rocks, however, except in a very few instances where mineralization has followed dike contacts for short distances. This relationship is rare and unimportant, in general, since but one fluorspar mine is situated on such a vein. The discovered vein width in this case is not great, but appears to be economical at least for shallow mining. It is held inprobable that the dikes, in general, will be fortunate prospecting grounds. The dike intrusions were distinctly earlier than the deposition of the veins, and indeed antedated the period of profound faulting, inasmuch as dike material does not occupy fault fissures.

Together with the Illinois field, the western Kentucky fluorspar district comprises the most important and available source of fluorspar in the United States. So long as the mineral is required for industries—and it is difficult to imagine a future lack of great industrial application for this only known source of the important element fluorine—the Kentucky field is assured of a market to the limit of its economic resources. Compared with the adulthood of development of the Illinois district, the Kentucky portion of the great fluorspar province is in a state of late youth in its progress. While no mines in this district have yet approached the importance of the developments at Rosiclare and Fairview, on the other hand the value of the field is demonstrated. The known areal distribution of workable fluorspar veins is greater in Kentucky than in Illinois, and it is believed that consistent and deeper exploitation of the major veins in Kentucky, together with an improvement in transportation facilities west and southwest of Marion, will greatly increase the importance of this State in fluorspar production. With the exhaustion of the big veins at Rosiclare and Fairview, Illinois, it appears that the Kentucky field will acquire leadership.

With a market which is chiefly eastern, competition of far western producers is of minor importance. Other sources for eastern consumers are Canada and England, requiring importations. It is not believed that either of these countries will give serious competition, though English spar will continue for a time to affect the eastern market. This situation will, of course, be largely controlled by the tariff duty rate.

A detailed statement of the statistics and economics of the industry appears in Chapter X.

CHAPTER II.

GENERAL GEOLOGICAL CONSIDERATIONS

Sedimentary Rocks

In this chapter will be reviewed very briefly the general geologic features that have obvious and direct bearing on the structure and origin of the fluorspar deposits. A detailed description of the regional geology cannot be given here; for such information the reader is referred to Dr. Weller's reports on the Golconda and Princeton quadrangles[1] which describe the various formations as they occur in those areas. The facts of stratigraphy apply as well to the rest of the fluorspar district.

The solid rock of the region consists, with the exception of a few small igneous bodies, of a very thick series of consolidated marine sediments—sandstones, limestones, and shales (consolidated muds). The individual beds making up this series are numerous and of various thicknesses as may be seen by referring to the stratigraphic column which is given on page 12 for convenient reference. All the members shown in this column are known to outcrop within the district. Below the lowest of these—the St. Louis limestone—other sedimentary formations exist to an unknown depth, but none of these outcrop within the fluorspar area.

The St. Louis and Ste. Genevieve limestones are of especial importance in connection with the deposits of fluorspar. Mining and prospecting developments have up to the present been most successful in veins which show either of these formations in the walls—at least in the foot-wall. Very seldom indeed have veins of economic width been opened between walls of higher horizons. An important exception to this will be discussed in a later chapter. The suggestion is that these lower, thick, limestones were more favorable horizons for the deposition of the valuable minerals, an interpretation which has been recognized by some operators, and has been used in prospecting. An explanation of the possible influence of these formations on original deposition will be offered on a later page.

[1] Stuart Weller. The Geology of the Golconda Quadrangle; Kentucky Geological Survey, Series VI, Frankfort, Kentucky. 1921. The Geology of the Princeton Quadrangle, same series, 1923.

Dr. Weller's Stratigraphic Column of Consolidated formations exposed in the Western Kentucky district.[1]				Remarks
		Formation	Thickness in feet	
Pennsylvanian system		Pottsville sandstone	200 or less	Youngest consolidated formation of the district.
MISSISSIPPIAN SYSTEM	Chester Series	Kincaid limestone	180 or less	
		Degonia sandstone	30	
		Clore limestone and shale	40	
		Palestine sandstone	60	
		Menard limestone	80 or more	
		Waltersburg sandstone	50	
		Vienna limestone	30	"Birdsville" series of Ulrich, U. S. G. S. Prof. Paper 36.
		Tar Springs sandstone	100 to 150	
		Gl n Dean limestone	60	
		Hardinsburg sandstone	100	
		Golconda limestone	80 to 170	
		Cypress sandstone	100 to 125	
		Faint Creek shale and limestone	20 to 40	
		Bethel sandstone	80 to 120	"Cypress" of Ulrich, Prof. Paper 36
		Renault limestone	68 to 80	
	Iowa Series	Ste. Genevieve formation: Lower O'hara limestone	20	Oolitic beds are characteristic of these limestones.
		Rosiclare sandstone	20	The Fredonia also carries considerable chert.
		Fredonia limestone	180 to 200	
		St. Louis limestone	350	Oldest exposed formation of the district.

The St. Louis limestone is usually recognized without difficulty.[2] In the deeply colored red surface clay derived from this formation an abundance of chert fragments is usually found, while the undecomposed rock is most commonly dark gray (bluish) to nearly black in color, is oftentimes very dense ("lithographic"), though with occasional layers that are distinctly crystalline. It is thick bedded as contrasted with some of the upper limestones.

The Ste. Genevieve limestone likewise weathers to a very cherty residual clay, brilliantly red in color. The undecomposed rock is very frequently extremely oolitic, a characteristic that is generally used in its recognition by prospectors. In this connection it will be important to remember that, as described

[1] Column taken from Kentucky Geological Survey, Series VI, 1921; Geology of the Golconda Quadrangle, by Stuart Weller, p. 12.

[2] See Weller's lithologic descriptions of the formations occurring in the Golconda quadrangle; Kentucky Geological Survey, Series VI., Vol. IV., 1921. Descriptions of characteristic fossils are also given.

by Weller, the formation contains some layers that lack this feature. The limestone is lighter in color than the St. Louis, but, like the latter, in places it contains frequent cherty layers. There are a few fossils which are useful in identifying these two formations. (See Weller's report.)

No attempt has been made in connection with this report to closely identify the formations occurring in the vicinity of mines and prospects visited, beyond a broad recognition of the Chester series, the Ste. Genevieve formation and the St. Louis limestone. Such detailed work is to be undertaken by the Survey at a later date. The term "Birdsville" the broadly inclusive term of Ulrich's earlier report,[3] and which denotes the Chester beds above and including the Cypress sandstone of Weller's column, is occasionally used herein in that sense. For prospecting the broad identification of "Birdsville" is insufficient.

Regarding the Chester series, the writer would call attention to its great thickness, and the frequent alternations of limestone beds—the majority of which are relatively thin—with sandstones and some shales that were less favorable formations for the deposition of fluorspar.

The Pottsville formation is found as a capping of some of the higher hills. It contains beds of conglomerate, sandstone, and shale; the conglomerate with its large quartz pebbles, and the coarse sandstone, appear to be relatively very resistant to the processes of erosion, and consequently their presence has resulted in the development of short high ridges and knobs on which these beds form a capping.

Structural Deformation

Except where deformed by faulting the beds are practically horizontal in attitude. Departures from this are apparently of slight degree or local, and are unimportant as respects the mineral resources.

Faulting

One of the features which notably distinguishes this area from other parts of the great interior plains province is the remarkable degree of faulting which the region has suffered.

[3] U. S. Geol. Surv. Prof. Paper 36, 1905.

In no other part of the great Mississippi-Ohio drainage area is there known to exist such a marked and concentrated system of fractures. The existence and character of these faults is closely linked with two other impressive features which also individualize this region, namely, the presence of igenous rocks and the concentration of the mineral fluorspar in some of the faults, both of which will be discussed in some detail. As an indication of the regional distinction the faults confer on western Kentucky, it may be pointed out that Weller's map of the Kentucky portion of the Golconda quadrangle alone shows at least sixty-seven of these breaks, while twenty-one prominent faults and many other minor slips are reported by Weller in the Illinois fluorspar district.[4] If faulted portions of the remaining three quadrangles in Kentucky prove to be fractured to a similar degree—and the Cave-in-Rock quadrangle (which in its western part contains most of the developed mines) appears to be even more severely disrupted—then a total of 150 to 175 faults for the entire region of fluorspar mineralization would be a conservative estimate. On the west and southwest of the fluorspar district faults of unknown extent have been reported, while on the east and southeast a few long breaks are reported to extend easterly making a more or less continuous zone of faulting that reaches central and eastern Kentucky.

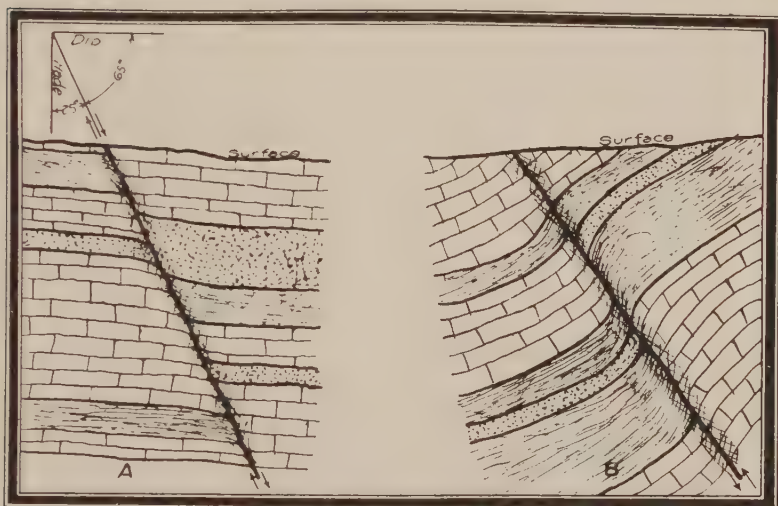
The trend or "strike" of the major faults in the fluorspar district is usually from North 20° to 60° East, except in the south and east, where the trends change to more easterly directions, even becoming east by south in the Fredonia-Princeton district. Shorter faults very frequently cross the blocks between major faults in northwesterly directions. Thus the entire region is a mosaic of elongate and wedge-shaped fault blocks with various amounts of displacement. The fault planes possess, in general, very steep dips; some are practically vertical in attitude, while most of the others vary from 70 to 85 degrees, few having dips as low as 65°. The direction of dip is not uniform, some of the major planes dipping to the southeast, others to the northwest.

The amount of displacement varies within wide limits,

[4] Illinois: State Geological Survey, Bulletin 41, 1920.

becoming as great as 1300 feet in the Golconda quadrangle (Weller). The magnitude of displacement, however, has no definite relationship to the amount of mineralization within the fault and great displacements may not be interpreted in the light of present knowledge as indicative of future success in mining.

Slickensiding is pronounced on most limestone walls, but discontinuous on any given wall. Sandstones also show this feature to some degree—in cases very pronouncedly—but very



2a. Diagram illustrating normal fault (a), and reverse fault (b). Arrows indicate relative directions of movement of blocks.

often these formations are greatly shattered and dragged. Brecciation of limestone walls as well as those of sandstone extends through wide zones, as much as 100 feet in places, but the fractured limestone is usually "healed" with calcite, while the sandstone breccia remains partially uncemented, though close to the fissures the fractures may be completely filled with quartz, and to a minor degree, with fluorspar. Shale beds show considerable "drag" as a rule, with very minor mineralization of the breccia.

The faults are of the normal, or so-called "gravity" type, that is, the hanging wall constitutes the downthrow side, so that at a given position on the fault the hanging wall formation is the younger. Conversely, when the relative ages of the wall rocks are known, the dip of the fracture plane is then known to be toward the younger rock. No "reverse" or "thrust" faults are known in the region. Fig. 2a illustrates the two types of faults.

The recognition of faults is of great importance because some of these fracture zones were apparently the paths of travel for the solutions that deposited the valuable minerals. In the Kentucky field all the known economic deposits are situated

(2b) Fault drag in sandstone ("quartzite"), showing characteristic tilting and brecciation of beds. On Moore Hill, 4 miles west (by south) of Marion.

between the walls of faults. The same condition practically holds true for the Illinois field, there being but two or three known exceptions. The writer has been unable to find any exceptions among the many mines and prospects examined in the Kentucky area.

Usually the larger faults of the district are not single breaks, but are zones of fracture, so that numerous fissures are associated and connected in a relatively narrow zone of definite trend. The minor associated fault surfaces may depart widely from the major direction, but many of them intersect at very sharp angles, while some run approximately parallel to the main fault surface for considerable distances. An example of such a zone of fracturing is the Larue system on which are located the Big 4, Larue, and other mines and prospects. At one of the positions on this fault, for instance, the main and a prominent subsidiary fracture have the relations shown in Fig. 3. Mr. A. H. Reed reports a very persistent nearly parallel fracture along the main fault in this zone. Whether or not the same susidiary plane continues uninterruptedly the writer cannot affirm. Other fractures enter the main fault at several points.

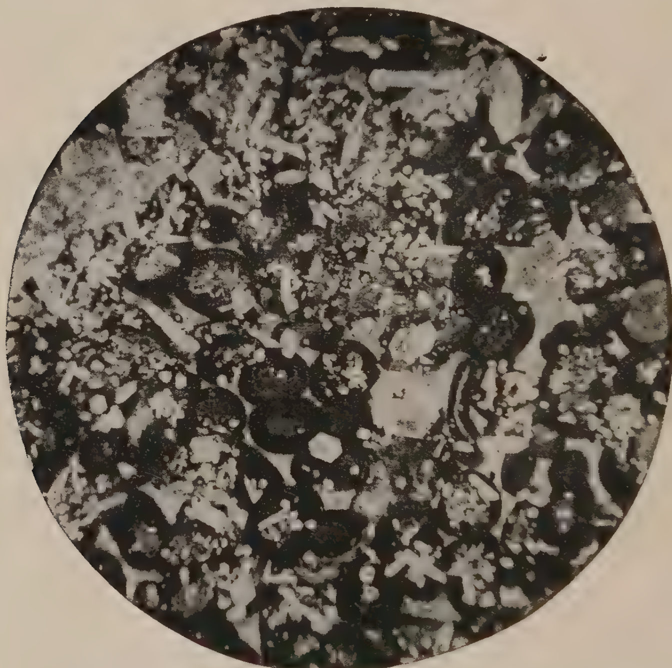
Faulting was not confined to a single period of dynamic adjustment, but has occurred during subsequent periods, probably continuing even to recent times, though with progressively decreasing intensities and frequencies.

3. Illustrative of main fault and a subsidiary fissure at one point on the Larue system.

Physiographic Expression of Faults

In a number of instances erosion has revealed the location of a fault by the development of a ridge. The feature is due to the superior resistance toward the processes of erosion and weathering of one wall block over the other, the more resistant rock being a quartzitized (silicified) sandstone. The metamorphism of sandstone walls by silicification is usual along the more pronounced faults of the region, and is less pronounced along minor breaks. The disintegration processes of Nature have very slight effect on such quartzites as compared with their influence on the softer and more soluble limestones and the shales, with the result that a limestone fault wall has frequently been reduced below an opposing sandstone wall even where the latter occurs on the downthrow, or hanging wall, side. The quartzite "reef" thus formed may be traced often for long distances along the course of the fissure and thus it becomes a distinct aid in the location and tracing of such fault outcrops as possess a sandstone wall at the surface.

The silicification, or "quartzitization," of sandstones along the faults is the result of deposition of silica in the interstices



(4) "Jasperoid" oolitic limestone; replacement of oolite (Frendonia) by quartz, along vein walls at Mary Belle mine. Photomicrograph x12.

of the originally porous sandstone. The silica was brought in, at least in part, by waters circulating along the fissures, for quartz crystals are found in places replacing limestone vein walls, and also as a vein mineral. An interesting illustration of limestone partially replaced by quartz is to be found in the Mary Belle mine, where parts of the Fredonia limestone—the foot-wall formation—have been so affected. Fig. 4 is a photomicrograph of a thin section taken from a specimen of this limestone. However, as a general thing the limestones show comparatively little silicification even where the opposing quartzite wall is strongly silicified. The hardening of the sandstones may therefore be due partly to the deposition of silica derived from the badly crushed sandstone itself under the influence of the heat and pressure of crushing, together with such heated waters as may have arisen along the fractures.

Along the quartzite ridges that thus mark the presence of faults, the fault planes will outcrop usually near the base or partly up the side, and will dip into the ridge when the other wall-rock consists of the St. Louis or Fredonia limestones.

(5) View looking west from "quartzitic" fault escarpment, Moore Hill, three and one-half miles west by south from Marion. Other fault escarpments appear in the view. In the distance rises the flat-topped Hardins Knob, one of the highest points in the county. The view shows characteristic topography of the faulted district.

Veins

The second distinctive geologic feature of this region is the strong mineralization of many of the faults. Waters circulating along these passages, and probably rising from great depths, brought with them quantities of calcium fluoride, lead and zinc sulphides, and other substances. By gradual decrease in temperature and pressure as they circulated to higher levels these solutions became supersaturated with the dissolved mineral matter which was thereupon precipitated, forming veins of fluorspar, galena, sphalerite, and other associated minerals, within the channels of circulation, namely, the fault zones. The close relationship between faults and mineral bodies suggests a genetic connection which is discussed later with other related facts.

The structure and mineralogy of the veins is taken up in Chapter IV.

CHAPTER III.

IGNEOUS ROCKS

The occurrence of igneous rocks in this district is the third phenomenon that characterizes this part of the Mississippi-Ohio valley region and gives it marked distinction. Dikes and sills have long been known to occur in the fluorspar area, and new discoveries are occasionally being made, increasing the significance of their presence in this mineral province. About twenty exposures have been recorded in the Kentucky district, and ten in the Illinois field. Of those in Kentucky, which are for the most part widely scattered, several may be exposures on the same dikes that are also exposed elsewhere, but the heavy layers or residual clay and other soils make it impossible to trace any of the dikes for long distances.

It is believed that these igneous bodies and the fluorspar veins probably have a close genetic relationship, the aspects of which are discussed in the chapter on origin of the deposits. It is not the writer's belief, however, that the position of the dikes in any way controls the position of fluorspar mineralization; the finding of a dike in no way supports belief in the presence nearby of a fluorspar deposit. It is true that in places a slight degree of mineralization has occurred along the walls of a dike. The known cases are rare, however, and mostly unimportant economically. Most of the dikes in Illinois and Kentucky apparently have no direct structural connection with vein matter, though as to what may be the case at great depths nothing can yet be stated. The period of most pronounced faulting and its later mineralization appears to have occurred subsequently to the intrusion of the igneous rocks, for the latter do not occupy fault zones of any appreciable magnitude, and also, in Illinois, veinlets of fluorspar have been found crosscutting a dike. Inasmuch as the fluorspar, therefore, was chiefly deposited in strong faults of later development than the intrusion of molten rock material, it is not to be expected that these two kinds of geologic bodies—veins and dikes—will commonly be connected structurally.

The concentration of zinc ore, without any associated fluorspar, has in two instances proceeded along or above dikes. The notable example of this is the Old Jim mine, about four miles west of Marion.

General Petrologic Description

The known Kentucky igneous rocks are chemically all very basic types, and of unusual mineralogic composition, a fact which would suggest very strongly that they were derived from a highly differentiated magma. The connection of this probable origin with that of fluorine-bearing waters is taken up in Chapter VI. They have been studied microscopically by several people. In 1890, J. S. Diller examined specimens of the Flanary dike that were collected by Dr. Ulrich and gave the name of "mica-peridotite" to the rock, which term significantly describes the variety;[1] W. S. T. Smith gives an inclusive desription of the dike rocks in the Professional Paper 36 of the United States Geological Survey; A. Johannsen's petrographic observations on dike-rocks from the Illinois field are given in Bain's report of that district,[2] and the Illinois rocks have also been briefly described by the writer.[3] The igneous rocks of the Kentucky area are similar to the coarser-grained types of Illinois, i. e., the Mix dike (mica-peridotite) and the Golconda dike (pyroxene-lamprophyre of Johannsen), both of which are the more basic varieties of the Illinois intrusives. No dikes of the Downey's Bluff type (dense-textured lamprophyres) have yet been reported in Kentucky.

The writer has not been able to make a complete study of the Kentucky dikes, an investigation which is contemplated for the future, but has been able to collect a few specimens sufficiently coherent to allow the preparation of microscope slides. In all cases so far observed and reported by previous workers the dikes correspond to the types mentioned above. The general description that follows is based in part on personal observations and in part on descriptions by previous writers.

Megascopically the rocks are of fine to medium-grained

[1] American Journal of Science, Vol. 44, 3d Series, 1892, p. 286.
[2] Op. Cit., pp. 28-30.
[3] Illinois: State Geological Survey, Bulletin 41, 1920, pp. 237-244.

holocrystalline texture. They contain very conspicuous foils of a dark brown mica, and sometimes an appreciable amount of small pyrite grains. Other minerals are usually indistinguishable, owing to the high degree of alteration that the rocks have experienced, but the very dark greenish color indicates the presence of chlorite and serpentine in large amounts. Veinlets of fibrous secondary calcite frequently cross the exposures. In some of the rocks the mica grains are seen plainly to be poikilitic in structure, the included grains being minute black crystals in some instances, minute white crystals in others. Occasionally the abundance of large brown micas with their included small grains gives the rock a peculiarly mottled, bronze appearance. The igneous rocks are readily recognized by their color and texture and also by their specific gravity which is impressively greater than that of other country rocks.

Under the microscope the most striking features are the abundance of apatite needles in some of the rocks, of small grains of magnetite and ilmenite with much associated leucoxene, the presence of moderate amounts of a brownish to yellow colored mineral of strong relief but sometimes nearly opaque, which is probably perofskite, and the absence of any feldspar grains. The brown mica is probably the most abundant primary mineral. It is light pink to medium brown in color, with appreciable but not strong pleochroism, the absorption never being as great as that of normal biotite. Johannsen has identified it as the phlogopite variety, indicating that the magma from which it was directly derived was strongly magnesian. A chemical analysis of the Flanary dike was made by the United States Geological Survey, and is here quoted from Diller's paper.[4] The Flanary rock is a typical illustration of the mica-peridotites of this district. The analysis indicates the altered condition of the

ANALYSIS OF THE FLANARY DIKE (from Diller).

SiO_2	33.84
TiO_2	3.78
Al_2O_3	5.88
Cr_2O_3	0.18
Fe_2O_3	7.04
FeO	5.16

[4] Am. Jour. Sci., 3d Series, Vol. 44, p. 288.

MnO	0.16
NiO	0.10
CaO	9.46
MgO	22.96
K_2O	2.04
Na_2O	0.33
H_2O	7.50
P_2O_5	0.89
CO_2	0.43
BaO	0.06
Cl	0.05

rock, but the low silica and alumina contents, and the high iron and magnesia contents are suggestive. The Flanary rock is not one of the apatite-rich varieties such as are found at several other localities. In some of the rocks remnants of a colorless, or nearly colorless, pyroxene are found. No olivine was seen in any of the Kentucky rocks by the writer, though numerous serpentine areas, by their shape and structure, suggest original olivine phenocrysts. Diller also confirms this. Referring to the Flanary dike he states: "The serpentine is distributed uniformly throughout the rock in irregular rounded or angular grains averaging 1 mm. in diameter. The characteristic sections with outlines like those of olivine parallel to the base and macropinacoid are sufficiently numerous and well defined to clearly indicate that the serpentine originated from the alteration of olivine. The large quantity of olivine originally present shows that the rock belongs to the peridotites."[5] As minerals of secondary development by alteration and ground water deposition, are found large amounts of serpentine and calcite, a variable amount of leucoxene, and some quartz. In places pyrite grains are fairly profuse, plainly replacing other minerals of the rock. It is not known whether any of the pyrite is original.

The rock readily succumbs to weathering, decomposing to give a dark brown clayey and slightly sandy soil, which usually contains unaltered mica plates. The mica flakes and color of this residuum usually serve to establish the presence of an igneous body, but the rock decomposes so readily that the solid material is very seldom exposed. In fact most of the reported

[5] Op. Cit., p. 287.

occurrences yield no signs of solid rock to the investigator, except where previous prospecting on the site has resulted in bringing such material to the surface.

The dikes are narrow bodies, though they may have very great extent along their trend. The widest observed by the writer was the exposure of the Old Jim dike in the abandoned open cuts about four and a half miles west of Marion. Here a badly weathered exposure was left standing in the center of the pit, from which a zinc carbonate ore-body was mined out on both sides of the dike. The width of this exposure is not over ten feet at the base. The Flanary dike was reported as being at least 15 to 20 feet in width, but recent information points to the probability that the course of the dike was previously reported incorrectly, and that its actual course may be far different, so that the original determination of width in a pit in which solid walls were not encountered may be correspondingly wrong. The View dike was prospected by pitting, and a width of 12 feet is reported for it. Other dikes appear to be much narrower in general.

The courses of the dikes, so far as is definitely known at present, are always northwesterly. The Flanary dike has been stated to be an exception to this rule, but three considerations make this interpretation doubtful. In the first place, as mentioned above, the walls of the dike were seemingly not discovered in the excavations that were made on it, and E. O. Ulrich has expressed his earlier doubt that the trend is northeasterly. (See Prof. Paper 36, pp. 101-102.) Secondly, Mr. A. H. Reed reports having sunk six prospect pits in positions that would indicate the presence of two parallel dikes at the supposed location of the Flanary dike, these bodies having a northwesterly trend. Thirdly, observations by the writer on two prospect pits at the supposed dike location, both of which showed very much weathered dike material in the dump piles, give a course between the two pits of N 17° W, a trend nearly parallel with the course of the Holly vein, which was supposed to cross the Flanary dike very close to the dike prospect. In a recent fluorspar prospect within a few hundred feet of the Holly vein, on the northeast side, and about a mile south by east from the Flanary dike prospect, the cross-cut has been driven through a small dike that has a bearing of approximately N 15° W. This dike may be the continuation of the Flanary, or of one approximately parallel to it, or of a diverging arm of it.

The dikes occupy fissures of little or no displacement, a condition which leads to the conclusion that the intense faulting of the region occurred subsequently to the intrusion of the igneous rock bodies.

Old Jim Dikes

These interesting igneous bodies are best seen at an abandoned open pit situated four miles due west of Marion. (See map I.) Here a considerable body of zinc carbonate was opened along the flanks of two intersecting dikes of mica-peridotite, the largest of which has a width of eight to ten feet. Several shafts were sunk along the course of these dikes which have trends of N 29° W and N 35° W. There are indications also of at least one more dike of very similar trend in this vicinity. The specimens taken proved to be very highly altered, but apparently the rock differs in no marked way from the other peridotites of the region. The hand specimen displays the usual texture with obvious mica plates and the characteristic dark greenish-gray color. Under the microscope a very large proportion of secondary calcite appears. The moderately pleochroic brown mica is abundant and shows more alteration than is usual. Apatite, in grains easily discovered with the medium power objective, is very prominent. Perofskite and a fairly large amount of leucoxene, a small amount of magnetite (or ilmenite) and a few grains of pyrite are present. Outlines of phenocrysts that may have been pyroxenes are entirely altered. Secondary quartz appears in small amount. Serpentine is a prominent alteration product, partly of the micas, and partly of some other original constituent which has been entirely replaced.

The pit is partly filled with debris, so that contacts between the dike and other rocks are not exposed. Fragments of marmorized limestone were found, however, that indicate the metamorphism of limestone to a depth of at least six inches, the resulting marble being well crystallized and white.

Ulrich's map indicates a possible length of five miles for the dike. It has not been definitely traced for more than a mile, though outcrops of several very small dikes and sills on the Belt farm along Claylick Creek, nearly three miles southeast of the Old Jim mine, may be connected with a continuation of the Old Jim dike, a fact which cannot be proved without detailed mapping.

Pyrite is said to have been found in large amounts at places on the dike at the Old Jim mine, and to be intimately associated

(6) Remnant of Old Jim dike, in abandoned open-cut of Old Jim mine, four miles west of Marion.

with, and disseminated in, the upper portion of the dike rock. The presence of much pyrite refuse and cinder-like masses of oxide of iron in the waste piles testify to the presence of large quantities of the sulphide of iron in the mine. Unfortunately the material cannot be seen in place and its true relations to the dike material and zinc ore body discovered, but the conditions described to the writer suggest a possible connection between the sulphide of iron and the sulphide of zinc from which the body zinc carbonate ore was probably derived. The ore as mined, was an earthy zinc carbonate, which was apparently limited in distribution to the surface zone. Sphalerite is said to have appeared below water level where the zinc carbonate ran out. The carbonate was undoubtedly a shallow zone feature derived by the oxidation and carbonation of original sphalerite, with concentration and replacement of the limestone at and above water level. Possibly circulating waters carried the zinc from major vein zones at the west, precipitating zinc sulphide where they met the dike material carrying the sulphide of iron. The fissures of access were the dike contacts.

Asa Belt Farm Sills, and Dikes of the Vicinity

Dr. Ulrich reported the occurrence of two sills on the Asa Belt farm, along Claylick Creek, three and a half miles southwest of Marion. His section of the exposure at this place is quoted from Professional Paper 36, and is as follows:

	Ft.	In.
Soil and loose sand rock at top. Fine-grained, thin-bedded argillaceous sandstone	6	0
Decomposed mica-peridotite	1	4
Shaly sandstone	0	9
Mica-peridotite	5	0
Slaty sandstone, upper 9″ blackened	2	0

In the bed of Claylick Creek, near the Belt Farm, and east of the Butler Farm, the writer has recently (July, 1922) observed exposures of several very narrow dikes in the creek bed. At one point, five dikes show, with width ranging from 4 to 12 inches. These beds are very closely spaced—from 2 to 30 feet—and are probably divergent from a larger dike. They occupy parallel joint fissures in limestone, and have a trend of N 20° W. The rocks are much decomposed, and are fine-grained as a result of the rapid cooling of these very narrow intrusions. Minute seams of fibrous calcite occur at or close to the contacts in some cases, a feature also observed in the large peridotite dikes. The limestone country rocks display no unusual shearing or other structural disturbances, so that these dikes were probably rather quietly insinuated along pronounced jointing. No microscopic examination of these has yet been made; megascopically they resemble somewhat the lamprophyric dikes of the Illinois field, carrying occasional small foils of dark mica and much pyrite. About one quarter of a mile north of these dikes, and also in the bedrock of Claylick Creek, another dike of the same trend is exposed having no observable contacts, but showing a probable width of three feet or more. This material is much coarser-grained than the dikes just described, and megascopically resemble in every particular the finer-grained mica-peridotes, such as the View dike (see below). No microscopic examination has been made.

Hard Dike

On the Hard Farm, two miles northwest of Marion, and at a point in the bank of the west branch of Crooked Creek, is a prospect pit, sunk in an outcrop of a very much decomposed dike, about five feet wide, and with a course approximately N 35° W. No indications of accompanying mineralization were seen. The rock was too thoroughly altered to provide specimens for petrographic study. It appears to be similar in its altered state to other bodies of altered peridotite.

Flanary Dike

The situation and course of this dike have already been described, and reference is made to the petrographic description by J. S. Diller.[6] Fresh specimens were not collected by the writer. Diller reports in part: "The rock is composed essentially of biotite, serpentine, and perofskite with a smaller proportion of apatite, muscovite, magnetite, chlorite, calcite, and other secondary products that cannot be definitely determined. It is possible that there may have been some pyroxene present. . . ."

Holly Dike

About a mile south of Sheridan, between the Big Four and Holly mines, and very near the Holly vein, the Crystal Fluorspar Company has recently opened a prospect shaft (1921), the crosscut from which cuts a narrow dike, previously referred to in connection with the discussion of the probable course of the Flanary dike. This body is about ten inches wide and has a

[6] Am. Jour. Sci., Vol. 44, 3d Series, 1892, pp. 286-289.

course of approximately N 15° W, with a very steep dip, 80°, of the poorly exposed contact plane toward the east. The rock is much altered, but distinctly similar to the usual peridotite of the country. The poikilitic micas and small white grains (leucoxene?) are visible in the hand specimen. A microscopic analysis is not yet available.

View Dike

About half a mile west of the cross-roads at View, on the Davenport land just north of the View-Salem road, the Lowery prospect shaft was sunk in dike material in the unsuccessful attempt to find a body of zinc carbonate ore. The course of the dike is given by Ulrich as N 30° W, and the width in the shaft 12 feet. The dump pile shows no signs of ore minerals or fluorspar. The microscope discloses the usual assemblage of minerals, with noteworthy amounts of small apatites, iron ore minerals, and leucoxene. Pyrite grains are prominent.

Dike East of Levias

East of the Eaton mine, which is about a mile east of Levias, the dump pile of a prospect shaft sunk in dike material shows dike rock similar in appearance to the Lowery shaft material. The microscope yields similar results except that in the less altered rock (from a drill-core) remnants of nearly colorless pyroxene are found. The rock also contains more pyrite, which is very evidently a late mineral, introduced subsequently to some of the alteration products and replacing them. Fluorspar, calcite, galena and sphalerite also appear in this pile of debris, as well as fragments of metamorphosed limestone. The prospect is very close to a zone of fluorspar mineralization which is undoubtedly responsible for the appearance of these vein minerals in connection with this dike. The course of the dike could not be determined. Ulrich gives it a northwesterly strike which, if carried southeasterly, would connect it approximately with the View dike. The distance between these two points would be about two miles. In the absence of accurate base-maps, and without sufficient available time for the necessary plotting, the correlation of dikes in this and in several similar instances could not be attempted. It is perhaps pertinent to remark here that in only very few instances would there be any probable connection between dikes and mineral bodies of economic importance. The significance of this is seen in the fact that, if these two dike prospects are in reality on the same single dike, the associated fluorspar mineralization is only local and confined to the vicinity of a pronounced zone of faulting and mineralization, so that the nearby shear zones—now partly filled with vein material—are responsible for the small amount of fluorspar-lead-zinc deposition near the dike.

Dike West of Lola

Dr. Stuart Weller reported to the writer the occurrence of a dike about a mile and a half west of Lola. Petrographically it is similar to the previously described types of mica-peridotite. The amount of apatite in the rock is small.

Dikes at Hudson Mine

The Hudson mine is located about three miles southwest of Salem. Here a deep open-cut has been developed through the mining of a body of zinc carbonate ore. The concentration of zinc was associated with two very narrow parallel dikes having a course about three to five degrees west of north. The dikes are extremely altered. No petrographic examination was made.

Miscellaneous Dikes

Other reported occurrences are the Cardin dikes, and the Caldwell Springs dike. According to Fohs [7] four dikes, closely spaced and approximately parallel with strikes from N 30° W to N 34° W, appear in fracture zones of some displacement on the Cardin and York farms one mile north of View. Ulrich also reports a narrow dike on the Cardin place with a course N 30° W.

The Caldwell Springs dike is described by Fohs as follows:

"West of Caldwell Springs, about one-quarter mile, on the east side of the branch and south of the church some prospecting immediately northeast of a sulphur spring and outcrop of St.

[7] Notes in office of Kentucky Geological Survey.

Louis limestone disclosed a dike several feet wide. After the removal of five feet of surface debris partially decomposed mica-peridotite in alternate green and yellow bands was exposed. These strike N 15° W which is assumed to be the direction of the dike. Deeper prospecting encountered fresher peridotite."

Concluding Remarks on Igneous Rocks

The igneous rocks that have been discovered up to this time in the Kentucky district were differentiates of a deep-lying magma. They belong to the general class of peridotites, but possess certain mineralogic peculiarities that give these particular peridotites distinction. Chief among them is the presence of a mica, either of the biotite or the phlogopite varieties, usually in prominent amounts, and in some cases in lavish abundance. A distinct poikilitic or inclusion texture of the coarse mica plates is the rule. Olivine was a fairly prominent original constituent of the dikes, but has since been almost completely altered to serpentine. A pyroxene, of variety indeterminate, very large quantities of magnetite and ilmenite or titaniferous magnetite, and perofskite (both partly altered to secondary leucoxene), and apatite, were primary constituents. The latter is practically always present, and in some of the rocks attains great prominence both in size of crystals and in quantity.

The mineral association, therefore, indicates differentiation of the deep-seated original magma, only the basic differentiate of which appears to be exposed in the Kentucky fluorspar district. It is possible, if not indeed probable, that the complementary differentiate of the original magma is represented in part by the great concentration of fluorine, now as fluorspar in the veins, and in part by the crystalline quartz of the vein matter. In addition, in the Illinois district breccias were noted whose texture and field relations strongly suggest volcanic action, and whose constituent minerals, though mostly altered, include slight amounts of microcline and other feldspars, biotite, and muscovite, normally constituents of acidic differentiates.[8]

That phlogopite is a very unusual constituent of igneous rocks is of general belief. Petrographers usually conclude the

[8] Illinois Geol. Survey Bulletin 41.

mineral to be characteristically of metamorphic origin, and rarely, if ever, of primary igneous origin. It is generally credited with being formed under the influence of the so-called "mineralizers," water and gases (fluorine, et al.).

Peridotite or lamprophyre dikes and fluorspar veins do not, however, necessarily occur in proximity, continuity, or other structural association, and the discovery of a dike should not give undue hopes to the prospector, nor lend enchantment to the prospective purchase of mineral rights. In a few instances a small amount of fluorspar mineralization has taken place along the borders of dike material. The majority of dikes are without associated fluorspar veins of any size. In at least two instances shallow depth zinc deposits have been mined along dikes, and in these cases it is possible that the zinc deposition was influenced by the presence of pyrite in igneous bodies. The case of the Old Jim mine has been briefly discussed. That the non-association of veins and dikes is to be expected will be better understood by realizing that the veins usually fill fault fissures, sometimes of great displacement, while the dikes have so far failed to appear as the fillings of fault zones. The period of dike intrusion appears to have preceded the period of faulting and mineralization. Such a sequence is in harmony with the order of events in other regions. The periods were distinctly, but not necessarily greatly, separated in time.

No fluorspar appears in the dikes as a primary mineral constituent. Veinlets containing fluorspar and calcite are known to parallel and cross dike bodies, a condition which clearly shows the time relationships between the deposition of the fluorspar and the intrusion of the dikes.

ADDENDUM:

Since the completion of this report, Dr. Weller has recorded another dike exposure in the Princeton Quadrangle (Kentucky Geological Survey, Series VI, Vol. 10, 1923), one and a half miles north of Bethany Church. Heretofore no igneous rocks had been found in this quadrangle. The strike of the dike has not been determined.

CHAPTER IV.

THE FLUORSPAR DEPOSITS

Mode of Occurrence

The western Kentucky fluorspar deposits occur as fillings and replacements in fault fissures. The veins thus formed show considerable variation in width and in mineral proportions, but show a consanguinity in their mineral contents and structural features, not only amongst themselves, but also with the veins of the Illinois part of this extensive mineral province. In Illinois, however, another type of fluorspar deposit exists which has not as yet been discovered in the Kentucky field by the writer, namely, the extensive horizontal replacements along limestone beds which have been described as "bedding deposits,"[1] and which are sometimes known as "blanket" deposits or "blanket veins." The type is not to be confused with the loose surficial gravel deposits, sometimes known locally as "blankets," and which are in reality only residual concentrations in surface clays at and above ground water level, due to the decomposition of the wall rocks of true veins.

It is seen that the Kentucky field, outlined geographically on the basis of all the known prospects where fluorspar has been obtained, whether in economic quantities or not, is greatly more extensive than the Illinois field, and contains countless more prospect pits and mines combined. Yet, in Illinois the development work has been carried to greater depths with more extensive drifting in single mines, and has thus disclosed for observation more mineralogic and structural features of the veins in that state than is true in Kentucky. In fact, the data revealed in the deep Illinois mines may be said to contribute more conclusively to the determination of possible extent of the deposits, to the understanding of the mineral relationships, and to the study of structural features, than any of the Kentucky openings.

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[1] Illinois: State Geological Survey, Bulletin 41, 1920, pp. 254-256.

Minerals of the Veins

The minerals found in the fluorspar veins are relatively few, and simple in composition. They are:

Fluorspar (fluorite)
Calcite
Galena
Sphalerite (zinc blende)
Barite
Quartz
Greenockite
Pyrite
Chalcopyrite
Smithsonite
Cerussite

Limonite, kaolinite, and probably many other minerals of ordinary weathering, also occur. On the Illinois side, stibnite was once reported, but this stands unconfirmed. The mineral has never been seen in the fluorspar district by the writer, nor, apparently, by previous writers.

Of chief economic importance is the mineral fluorspar. The lead and zinc minerals are recovered as by-products, and never are the chief objects of exploitation, owing to the irregularity of their occurrence and the small total amounts in any one vein. Barite has been recovered and marketed in the past, but is of very minor importance. The calcite finds no market and is excluded as waste.

THE NON-METALLIC MINERALS

Fluorspar (fluorite; locally, "spar").

Composition. Calcium fluoride (CaF_2), 51.3% calcium, 48.7% fluorine. Easily recognized by the following characteristics: glassy luster; perfect octahedral cleavage (four directions of cleavage planes), easily cleavable; easily scratched by knife blade; usually translucent or transparent; commonly massive, but also occurring in cubical crystals; colorless, tinted, or deeply colored in shades of purple, violet, blue, red, and yellow. Specific gravity, 3.18 (Dana).

In these veins, the mineral occurs in great masses not showing the cubical crystallization except where crystals line the walls of cavities. Crystals of free growth are generally colored, or partly colored, usually with bands of color paralleling the crystal faces. Also, purple colors usually characterize the narrow veinlets that occur in the fractured limestone and shale walls, more rarely in the quartzites. The narrow veinlets that cross and replace calcite patches of the wall rock breccias are also frequently colored in shades of blue and purple. The larger masses of fluorspar, on the other hand, are of the white, yellowish, or brownish varieties.

Fluorspar makes up the bulk of the developed veins, though at local points in the veins the mineral is often subordinate to calcite or is even wanting. It is intimately associated with the calcite, replacing the latter mineral in an irregular manner, a feature which is further described under "Paragenesis of Minerals." Of varying width in the veins, it widens and narrows along the course of the fissures forming more or less connected lenticular "ore" bodies. This feature and the irregularity of the lenses are so marked as a rule that the accurate determination of ore reserves in a given mine is difficult.

The fluorspar masses are sometimes sheeted, caused by shearing movements subsequent to their deposition. A so-called "ribbon" structure results in which the bands may be very narrow, of the order of a quarter-inch or less, or wide, of the order of a foot or more. Lead and zinc sulphides have frequently been introduced along these shearing planes, and sometimes quartz in microscopic crystals has been brought in. (See discussion of silica contents in fluorspar under "Quartz.")

The mineral as mined is sometimes very pure, running as high as 98% or more calcium fluorite. Usually the mine product requires washing or jigging in order to bring the material up to standard grade. On the whole, however, the Kentucky-Illinois fluorspar is exceptionally pure mineral. Even in the deeply-colored "spar" coloring matter is present in such exceedingly small amounts that it rarely affects the commercial purity of the product. There should be no objection to the colored spar on the part of consumers, except in cases where the color is "spotted" and appears to be due to the presence of included crystals of pyrite or chalcopyrite.

Aside from the white, yellow and brown shades the most common colors displayed by the mineral are shades of violet and purple, but deep blue and reddish shades are not uncommon. Amber-colored fluorspar is sometimes found, as well as very light tints of blue and green. It is, indeed, unfortunate that the softness and cleavability of the mineral prevent its use for ornamental purposes. Few minerals known occur in such strikingly colored crystal groups as fluorspar. The colors have been variously attributed to hydrocarbons, the presence of metallic oxides or salts, the presence of rare metals, and differences in ionic states, but the real cause or causes are yet to be established. In this connection two interesting phenomena have been observed by the writer. The first is, that the very deeply-colored violet varieties, which generally result from deposition in narrow fissures of limestones and shales or by replacement of limestones commonly give a strong hydrocarbon odor upon being freshly broken. The odor very quickly dissipates. This condition has been consistently reported by previous investigators. The second coloration phenomenon was observed on four small crystal fragments. Small chalcopyrite crystals embedded in the surface of the fluorspar crystals were surrounded in each case by a narrow halo of deep purple color which shaded into the nearly colorless fluorspar mass. Small pits, which from their size and shape evidently once contained sulphide grains, were surrounded by similar halos. It is perhaps reasonable to draw the conclusions that some types of coloration are due to hydrocarbon compounds, and that others are due to the presence of metallic compounds or metallic ions in the depositing solution. It is to be noted that the deep violet varieties, which so persistently give off hydrocarbon odors upon being broken, are easily bleached in sunlight or under moderate artificial heating, the mineral thereby losing all color. Regarding the influence of metals or metallic compounds, one cannot state whether the color is the result of diffused metallic ions, atoms, or molecules, or whether the presence of metallic salts in the fluoriferous solution induced a particular ionic condition. So far as the effects on commercial purity of fluorspar are concerned, however, there appears never to be an appreciable amount of impurity to which even the deepest colors are attributable. The coloration is sometimes uniformly distributed, and sometimes arranged in sharply defined bands within the crystals and parallel to the cubic faces. It is very commonly found that crystals are strongly colored on the faces and at shallow depths into the crystals, but that the interior portion is very slightly tinted or colorless.

The intimate association of the fluorspar with calcite and other minerals in the veins makes it usually necessary to mill the mine product before shipment.

Fluorspar suitable for lens manufacture is sometimes found as crystals lining cavities in the veins. The specifications for fluorspar of this type—"optical fluorspar"—are briefly reviewed in Chapter X.

Calcite (locally "calc").

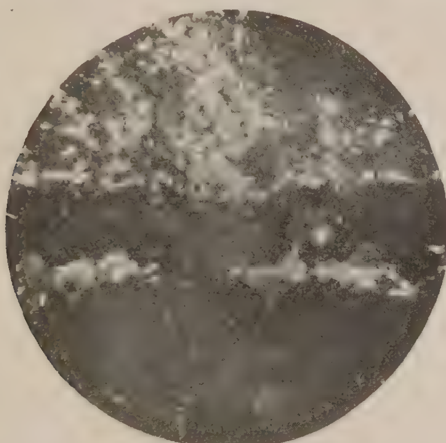
Composition: calcium carbonate ($CaCO_3$); identified by its cleavage, hardness, and reaction with dilute acids. Usually milky-white in color and opaque to translucent, but also found colorless and transparent. Colored varieties do not occur in these deposits. The mineral possesses three planes of perfect cleavage (three directions of cleavage planes within a single crystal or grain) and the cleavage planes make larger angles with each other than do those of fluorspar; the cleavage form is thus a rhombohedron (possessing six faces) contrasting with the tetrahedron (four faces) and the octahedron (eight faces) which are the cleavage forms of fluorspar. Its hardness is slightly lower than that of fluorspar, the mineral being very easily scratched by knife blade. Specific gravity, 2.714 (Dana). It reacts with dilute hydrochloric and nitric acids, effervescing freely.

The calcite of these veins is usually massively developed in large interlocking rhombic grains. The structure is very compact in most places, somewhat porous in some parts of the veins. Everywhere it shows very prominently its rhombohedral form. In open cavities the sharp-pointed scalenohedral crystals are often found, which are of a distinctly later generation than the vein calcite. The size of the grains in the massive granular aggregates of the veins is greatly variable; sometimes the individual grains reach maximum dimensions of five or six inches, while the more common sizes range from one to three inches in diameter.

The mineral is especially abundant in those portions of veins that lie between limestone walls, and particularly where the very thick, lower limestones (Ste. Genevieve and St. Louis) form the walls. In higher horizons not only is less of the mineral encountered, but it is frequently wanting between shale or quartzite walls. Here, too, the average total vein widths are less. The presence of calcite seems to have been more dependent upon the character of the adjacent walls, than upon solutions which would transport it for long distances. It very often cements a breccia of limestone fragments. Its position in the veins with reference to the other vein minerals is not constant. Within the vein matter one of its characteristic occurrences is as rounded included patches of spotty distribution. Horses of it occur more or less centrally located, with fluorspar passing between them and the walls. The contacts between the two minerals in such cases is very irregular, except where calcite bodies have been brought into juxtaposition by shearing subsequent to the formation of the veins. More generally, calcite appears irregularly distributed along the walls, while fluorspar occupies the intermediate zone. Calcite forms the entire vein filling in some instances. Finally, the mineral fills the multitudinous fractures that were developed in the limestone walls during the period of faulting. Such "healing" of the limestone is sometimes present for distances of fifty to a hundred feet from the main vein; these narrow, vertical, calcite "gash" veinlets are the usual phenomena in the limestone walls of the major veins, and sometimes also accompany the minor veins, though to a much less marked degree. In these veinlets it is usually not associated with fluorspar except close to the main fissure.

The calcite is removed from the mine product by jigging. The separation is never complete, but a small amount of calcite is not chemically detrimental in fluxing grades of fluorspar. It has economic value only when very pure and perfectly white. A small amount of calcite is marketed from the Central Kentucky district, but the present demand is very limited, and the requirements for purity are severe. While a great deal of the calcite associated with the fluorspar appears, without analysis, to be pure enough for the market, it is questionable whether it could be economically concentrated.

The calcite rhombs of the veins are commonly penetrated by irregular veinlets of fluorspar and other vein minerals; the fluorspar veinlets sometimes distinctly follow calcite cleavage planes, widening irregularly along them, and including patches of the calcite. The fluorspar is considered to replace calcite to a large extent, a phenomenon which is described in detail later.

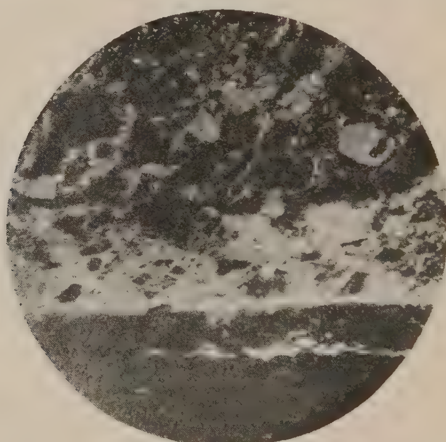


(7) Photomicrograph (x12) of fluorspar (dark) with small quartz crystals (light) along shears, and disseminated in fluorspar. Some grains of zinc blende (gray) associated with quartz. Polarized light, crossed nicols.

Quartz.

Composition: silicon dioxide (silica), SiO_2. Glassy; in the vein usually colorless transparent crystals, and of microscopic sizes. Hardness, greater than knife blade. Crystals in hexagonal shapes, sometimes found in druses along the walls of fractures and cavities, especially in association with sandstone walls.

Quartz is a very undesirable substance in the fluorspar deposits, inasmuch as the industrial specifications limit it to 5 or 6 per cent in fluxing grades, and to less than 1 per cent in "acid spar." The mineral is never prominently visible in the vein matter, but is rather to be discovered by microscopic examination. It is not uniformly present, nor uniformly distributed in the vein matter where it is present. Fairly large portions of some veins carry silica in undesirable amounts, and in cases its presence has prevented the marketing of the fluorspar without the admixture of high grade non-silicious "spar" to dilute the silica contents. Partly, of course, the silica content is due to the presence of silicious rock fragments, especially sandstone or quartzite, that have not been removed during the processes of mining and milling. A microscopic examination of thin sections taken from specimens of vein material has shown, however, that the silica content is probably often due to microscopic crystals of quartz disseminated in the spar and especially situated along



(8) Photomicrograph of fluorspar (black) with considerable quartz, introduced along fissures, with sulphides, and replacing fluorspar.

minute fractures. The photomicrographs, Figs. 7 and 8, show such quartz crystals in a fluorspar matrix. From such fluorspar the silica cannot be mechanically removed. Lumps of "ore" that have appeared to be of very high grade have been said to be remarkably silicious. This condition of minute quartz crystals intergrown intimately with the fluorspar is probably the explanation of many of the analyses that have shown silica content far in excess of what was confidently expected by the shipper.

Entirely considered, quartz is very subordinate as a gangue mineral in the deposits; it is not uniformly distributed, but locally may occur in amounts that bring the fluorspar below the standard for fluxing grade.

Barite (barytes; heavy-spar).

Composition: barium sulphate, $BaSO_4$. Massive, or crystalline, coarse to fine-grained crystalline aggregates. Hardness about the same as calcite, sometimes slightly softer. Specific gravity, 4.3-4.6 (Dana), distinguishing it from other non-metallic minerals of these deposits; also its non-effervescence with acid distinguishes it from calcite. It usually displays a pearly luster. Possesses three directions of cleavage with two right angles and one oblique angle, but in the massive aggregates these directions are not distinctly identified. Crystals are transparent to translucent.

When pure the mineral is white and opaque, but only freshly broken surfaces of the larger nodules that are obtained in this region display lustrous white surfaces. Generally it is more or less discolored with yellow, brown, or red iron stains, due to its occurrence in the clays of the zone of oxidation. As a primary vein mineral, it has not been seen in the solid vein material by the writer. It appears in the decomposed and disintegrated upper zones of the veins, and not in the portions of the deposits that lack the solution channels of downward percolating waters. It may have been concentrated, therefore, by ordinary ground waters, in which case it will be absent at depths where perfectly solid walls enclose the veins. The depth of weathering and decomposition of limestones varies greatly in the region, becoming as great as 200 feet at some places in the vicinity of Mexico, to which depths also the barite may be confidently expected to be present. It is not of universal distribution in the area, however, for in most of the deposits examined it is entirely lacking. Its more prominent occurrences are in the district just north of Lola, in portions of the Mexico district, along the "Tabb" and "Hodge" faults, and in the Fredonia-Princeton district. It has been mined to a slight extent, but only fitfully and in unimportant amounts. It is generally found in the residual limestone clays, though it is also present in the fluorspar bodies where the walls are only partially weathered. As seen in vein faces, it occurred with the usual red clay mixed with more or less fragmental fluorspar. Its vein relationships could not be definitely made out. In some instances, nodules of barite were found to be crossed by very narrow veinlets of perfectly colorless fluorspar, the latter being of apparently later development, and possibly representing a secondary deposition of "spar."

The barite is detrimental to the value of the fluorspar product, and must be removed by milling.

METALLIC MINERALS

Galena (Galenite).

Composition: lead sulphide, PbS; 86.6% lead when pure; may contain silver and other impurities.

Occurs in cubical crystals, and possesses perfect cubical cleavage; lead gray in color, with a high metallic luster, but tarnishes readily; hardness is slightly less than that of calcite—very easily scratched by knife-blade; heavy, its specific gravity being 7.4-7.6 (Dana).

It occurs in the fluorspar deposits both in crystal and in massive forms, the masses always showing the prominent cleavage faces. In some places it is fairly well disseminated in the fluorspar, and sometimes in the calcite masses, as relatively small crystalline grains. In places the masses of galena may be very large, forming so-called "pockets of lead" in the center or along one wall of the vein. Occasionally it is the predominating mineral in local portions of a vein, but is never found in sufficiently great concentration in a vein to warrant exploitation chiefly for its recovery.

The most prominent structural relationship of the galena to the rest of the vein matter is the development of the mineral along fractures and "slip planes" formed subsequently to the main deposition of fluorspar. It commonly occupies the "center slips," and also runs as irregularly trending veinlets across other vein matter, sometimes within the vein matter, sometimes along the walls, widening out in places into the larger accumulations or pockets.

It is pronouncedly associated with sphalerite in some deposits, the two minerals being intergrown. Rarely, it also contains a few small grains of pyrite or chalcopyrite.

Well-formed crystals may sometimes be found in cavities of the veins.

Its general disposition suggests that it was deposited chiefly after the fluorspar.

The galena of these deposits, while never containing large amounts of silver, is nevertheless more argentiferous than the galena of other Mississippi Valley lead deposits. Bain reports silver values up to 14 ounces per ton of galena for the Kentucky-Illinois district.[2] Regarding the silver content of galena in southern Illinois and western Kentucky, the United States Geological Survey reports the following:[3] "The galena of southern Illinois is notably argentiferous as compared with the rest of the Mississippi Valley ores, the silver content being as much as 14 ounces (fine) per ton of lead concentrate, and averaging for the last seven years from 5 to 7 ounces per ton of lead concentrate. The galena recovered" (referring now to western Kentucky) "is argentiferous, the silver content varying from a very small quantity to more than three ounces a ton, but no recovery of this silver content has been reported by the smelters during the last eight years." Finally, J. M. Blaney, Jr., of the Fairview Fluorspar & Lead Company reports[4] that the lead concentrates, 75 to 80% galena, contain 7 to 8 ounces per ton of silver. This distinction among Mississippi Valley deposits is considered to have genetic significance.

Lead concentrates are recovered at local mills, but are apparently of small importance as by-products, except occasionally when unusually large concentrations are encountered in the mines.

Sphalerite (Zinc blende; "jack").

Composition: zinc sulphide, ZnS; 67.0% zinc when pure. Occurs in various forms of isometric crystals, and possesses prominent dodecahedral cleavages. It is easily identified by its resinous or adamantine, non-metallic luster, presence of cleavage, colors, and hardness. The mineral has about the same hardness as fluorspar. The colors are variable, but usually

[2] See Bain, op. cit., p. 28.

[3] Mineral Resources of the United States, 1919, 1:13; Silver, Copper, Lead and Zinc in the Central States in 1919; J. P. Dunlop; pp. 246-247, and 251.

[4] Engineering and Mining Journal, January 29, 1921.

shades of yellow, brown, or red, or sometimes nearly black (variety "black jack"). Small fragments are usually transparent or translucent. Its specific gravity is 3.9-4.1 (Dana).

Sphalerite in these deposits occurs in a manner similar to that of galena. Its distribution is very irregular, being absent in parts of veins that in other parts contain an abundance of the mineral. Like galena, it often follows fractures in spar and calcite bodies, replacing these minerals irregularly but probably less intensely than does galena. The mineral is as widely distributed in the district as galena, but some veins are particularly characterized by its presence, while at a few long-abandoned prospects the dump piles showed it entirely without any associated fluorspar or galena. There was no access to underground workings at any of these places. It is said that there was a complete absence of fluorspar underground. This condition would seem to indicate that part of the sphalerite, at least, was deposited at a distinctly different period than the fluorspar.

Very thin irregular veinlets frequently fill contacts and small fractures in massive fluorspar. It is also dispersed in calcite and limestone breccias along fracture zones, sometimes representing a considerable local concentration. With the exception of the Old Jim Deposit, where it appeared at the bottom of the carbonate ore, its deposition, like that of fluorspar and galena, was apparently associated with deeply-extending fissures.

The mineral has some value as a by-product, although owing to difficulties in making a separation between it and fluorspar its recovery has not generally been attempted. (See under section on "Milling.") Like galena, it appears in such minor amounts anywhere in the district that exploitation primarily for this mineral is inadvisable.

Other Sulphides.

Pyrite, the pale brassy yellow sulphide of iron (FeS_2), and chalcopyrite ($CuFeS_2$), the brassy-yellow copper-iron sulphide, are present as small grains associated with galena, or minute crystals included within masses and crystals of fluorspar, or even very subordinately in veinlets of fluorspar replacing calcite. Both may be considered as very rare. The grains usually average about one-sixteenth inch in diameter and are disseminated. They are seldom conspicuous.

Pyrite is commonly found in small grains in the limestones close to the contacts of igneous rocks, and distributed in the igneous rock material. At the Old Jim mine it has been found in large quantities. Here, however, fluorspar is entirely absent.

Stibnite, the sulphide of antimony, has been reported to be present in the Fairview mine in the Illinois district but the writer has not discovered it either in Illinois or Kentucky.[5]

Metallic Carbonates.

The carbonates of zinc and lead, smithsonite and cerussite respectively, are found in the weathered and oxidized upper portions of the veins. Here the original metallic sulphides were altered through the agencies of atmospheric oxygen and ground waters carrying oxygen and carbon dioxide. Representing the oxidized portions of the deposits, the metallic carbonates occur only to shallow depths, in this region being mostly confined to depths less than 200 feet, although the presence of very small amounts of these minerals is to be noted occasionally at deeper levels. The depth to which appreciable oxidation and carbonation have taken place is roughly measured by the depth to which the limestone walls have been decomposed through the solvent action of the circulating ground waters of meteoric origin. In some mines this upper zone of decomposition is very shallow, and solid walls of limestone are encountered at depths of fifty feet or even less, as at the Holly Mine. Other mines are noted for the comparatively deep zone of mantle clay which may reach to depths of 150 feet or more. Especially is this true of the group of mines south and southwest of View. Solution channels in the limestones and more or less open shear planes allow ingress of surface waters to much greater depths at which minute quantities of the carbonates may appear on the surfaces of the metallic sulphides. On the other hand, the sulphides are always present even at the surface, never giving place entirely to the products of oxidation and carbonation.

Cerussite, the carbonate of lead, is never abundant in the

[5] See Bain, op. cit., p. 39.

deposits, even at the surface, and its appearance is of scientific rather than of technical interest. Lead carbonate, in contrast with zinc carbonate, is relatively slow to form, nor does the metal lend itself with ease to transportation by oxidizing waters. In the fluorspar veins the original sulphide masses rarely have been completely replaced by the carbonate, nor has there been apparently any appreciable removal of the metal from the upper parts of the veins. Large crystals of cerussite are rarely found, the mineral appearing as minutely crystalline "drusy" coating on galena masses. It is usually stained yellowish-brown by limonite. Its occurrence as porous surficial coatings on the galena and its high specific gravity help to identify it.

Smithsonite, carbonate of zinc, occurs in association with zinc blende, the relationship of these minerals being similar to those of galena and its oxidized product, cerussite. In addition it has been found concentrated in fairly large masses that are for the most part lacking in the sulphide of zinc. In such situations it probably, in part at least, replaces limestone, as at the Old Jim mine. It has in several places been sufficiently concentrated to permit economic exploitation solely for its recovery. Such deposits are always shallow, being confined to depths of the order of fifty to seventy-five feet, below which the deposits disappear completely or change to minor concentrations of zinc blende. The carbonate of these deposits is massive and minutely crystalline, stained with limonite. In form, besides the compact very fine granular type which prevails, are found stalactitic and botryoidal masses light brown to gray in color, sometimes pinkish. While the specific gravity of the mineral smithsonite is noticeably greater than that of the common rocks, these carbonate ores possess a marked porosity, so that "float" specimens are easily passed by without suspicion of valuable metal content.

Miscellaneous Minerals.

The green basic carbonate of copper, malachite, is sometimes found in the oxidation zone as thin films or stains along fractures in the other vein minerals. It is derived from the chalcopyrite grains occasionally found among the primary sulphides. It is never prominent.

The presence of several other secondary zinc and lead minerals has been reported. Among them are hydrozincite, calamine, and pyromorphite.[6]

Structure of the Deposits

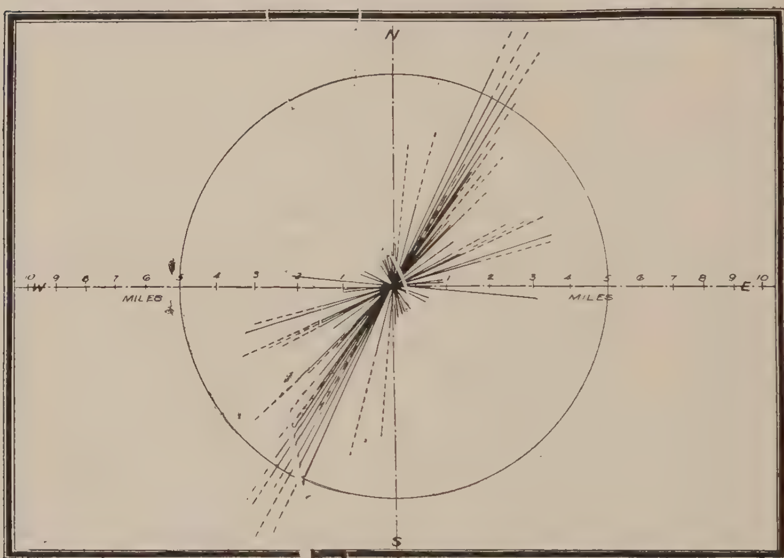
Genetically, there is but one type of mineral deposit in the district, i. e., the fissure vein, a thin tabular or sheet-like deposit occupying a fissure in the country rock. In this case the veins are partly "filled veins," the minerals having been deposited in more or less open fissures, and are partly replacement bodies. Essentially they are fissure fillings, but replacement of calcareous material has played a very important role in the development of economic mineral bodies. Unlike typical replacement veins, however, this process has not operated far into the wall rocks, but is rather closely confined to the fracture zones. In a practical mining sense, the fluorspar deposits may be considered as of two types: (1) solid veins; (2) "gravel" or superficial deposits. The superficial deposits in all cases originate by the decomposition and disintegration of solid veins exposed in the surface zone, i. e., to depths where downward percolating meteoric waters, assisted by the various weathering processes, destroy the solid wall rocks and allow the vein matter to become more or less dispersed through the clay and soil overburden. This process operates from the surface to slightly below ground water level, so that this type of deposit is very limited in depth. The usual depth to which limestone wall rocks are thus affected is of the order of 25 to 50 feet, though not infrequently it reaches greater depths, and in a few instances, as at the Susie Beeler mine, the limestone walls have been considerably affected to a depth of 200 feet. However, in spite of this relatively great depth, the superficial or "gravel" deposits are in most cases shallow mining propositions adapted to open pit mining methods.

CHIEF STRUCTURAL FEATURES OF SOLID VEINS.

Trend. (*Strike*). The majority of the veins have trends of widely varying northeasterly directions, becoming roughly easterly in the southeastern part of the area. Frequently the longer

[6] Ulrich and Smith; U. S. G. S. Prof. Paper 36.

northeasterly faults converge into sharp angles of intersection; in the vicinity of such intersections short cross faults and divergent faults of varying directions, mostly northwesterly, are to be expected, and may be locally as well mineralized as the major faults between which they extend. It is probable, however, that the long northeasterly fissures were the chief paths along which the mineralizing solutions circulated and deposited their loads.



(9) Strike plot of faults in region C (Weller), Golconda quadrangle.

The relative directions of the major and cross faults are brought out graphically by a strike plot of the forty-two faults of the Golconda quadrangle region C.[1] Fig. 9 is a reproduction of the plot made from data given in Weller's report. While this fault region is one of the minor belts of the fluorspar district (the Lola district, see Chapter VII), it is adjacent to and extends into one of the two most important belts of mineralization (the Marion-Sheridan district), and is chosen for this representation because of such proximity, and because it comprises 63 per cent of the faults of that quadrangle. In region C the faults are

[1] See Weller's fault map, Golconda quadrangle report, op. cit.

pronounced, closely spaced, and cross faults are numerous. It is believed that this strike plot will be typical for the entire fluorspar field, except that toward the south and southeast—in the Mexico and Princeton districts—the average bearings of the fault groups will become progressively more easterly. Unfortunately, data are not yet available for accurately plotting faults in the main fluorspar belt outside the Golconda quadrangle.

The forty-two fault directions plotted appear to fall into two chief groupings. The one, comprising the major faults, has bearings varying between N 25° E and N 47° E, with a probable average strike of about N 30° E. The second group, comprising chiefly short cross faults of one-third to three-fourths of a mile in length, has bearings varying from about N 10° E to about N 34° W, with a probable average strike of approximately N 15° W. A third, less distinct but nevertheless obvious, group consists of faults varying from one-half to four miles in length, and with an average strike of, roughly, N 65° to 70° E. This group includes some cross faults, and some of the less extensive major faults.

Dips.

The major faults usually have attitudes varying from a dip of 60° to vertical; dips from 70° to 85° are predominant, while some as low as 50° are noted on minor associated faults. The dip is not necessarily constant in any given vein, but may vary considerably; thus the dips at the Yandell mine are reported by Smith [8] as between the limits of 55° and 60°, the old Memphis mine (abandoned) 53° and 85°, with an average of about 60°, and the Hodge from 75° S. E. to 88° N. W. Variable dips are indeed the rule; and such marked variations as at the Memphis are usually to be attributed to subsequent displacements. The minor parallel and intersecting veins may frequently be found to dip at lower angles than the major controlling fissure, and toward the latter; on the Deer Creek properties a minor break—possibly the alleged "Glendale" fault—at an exposure dips northwesterly 51° toward the nearby main La Rue fissure which dips 70° toward the southeast. At the Lucile mine

[8] Prof. Paper 36, op. cit.

the principal dip appears to be about 70°, but here variations occur obviously due to pronounced subsequent shattering and dislocations. In the Mexico district dips of approximately 65° are noted, as at the Keystone mine; whether or not this is common to all on the Tabb system cannot be stated, but at the Haffaw mine near the eastern end of this system the dip appears to be rather uniform at 75° northwesterly, which may well be the dip of the chief fissure along the Tabb system judging by the comparative disclosures in the Haffaw and several other mines on this system. At the Mary Belle mine (Marion-Sheridan district) the vein has a general dip of nearly 75° N W; at the nearby Columbia the average is reported as 83° by Smith.[9] Seventy-five degrees is the reported dip for the vein at the Commodore mine, a few degrees greater than at the La Rue mine, and the same system, but 2½ miles from the latter.

Thus there appears to be no regularity of dips in the major veins other than the general limits stated above, except that few will be found with dips under 60° and over 80°. The minor associated fissures will range from 50° to 90°.

There appears to be no general rule of dip direction of the major veins; the La Rue major fault dips to the southeast, the equally well developed Columbia to the northwest.

Mineral Bodies.

Owing to the sinuous course of the major faults and the fact that some horizontal displacement as well as vertical has occurred in their formation, the mineral bodies of the veins characteristically pinch and swell, never maintaining a uniform width. The "ore" bodies may therefore be described as thin lenticular bodies more or less connected throughout the vein course. In the Mary Belle mine the "pinches" and "swells" are numerous with maximum widths of ten feet; this variation is less pronounced here than at other mines on major veins. At the Keystone Fluorspar Company mine, Mexico district, the greatest width noted was 12 feet; the nearby Tabb mine of the West Kentucky Ore Company reports a maximum width of 17 feet. At the Commodore mine on the La Rue fault a vein width from 0 to 26 feet is reported. This amount of variation appears to be unusual.

[9] Op. Cit.

As a rule the Kentucky veins may be said to vary in width from a few inches to 12 feet with an occasional "ore" body of greater width.

Variability of width in the fluorspar bodies is also due to the variable degree of the replacement of calcite and limestone by fluorspar. The irregular replacement ore-bodies may comprise the entire vein width, being limited sharply in places by the impermeable gougy selvage of slickensided walls, and where these are absent extending irregularly into the limestone wall rock, or they may thin out and disappear entirely leaving calcite in sole possession of the vein.

The lenticular forms of the vein fillings are therefore chiefly attributed to two causes, the structural sinuosity of the faults and the replacement relations between the fluorspar and the calcite or limestone walls.

Wall Features.

Brecciation of the walls is most pronounced in the horizons of sandstones and silicified limestones. The normal limestone walls always show some brecciation with the development of narrow closely spaced fissures mostly occupied by calcite veinlets. The brecciation of limestone is on the whole less pronounced than that of the sandstones. Shales show a considerable amount of close shearing and distortion with little accompanying development of fissures. Drag features are most prominent in the shales, pronounced also in the sandstones, and least evident in the limestones.

Walls of all types display slickensiding. Limestone walls are frequently greatly polished with the development of a compact and very thin gouge; shale walls are less persistently slickensided, and the thick gougy material less compact; sandstone and "quartzite" walls are often deeply grooved, rough, and without persistence or the gougy selvage.

Vein minerals penetrate and occasionally impregnate the wall rocks, except where these are protected by a compact or a thick gouge. Penetration of the limestone by the calcite and fluorspar as veinlets and minor replacement bodies, and of the shales and sandstones by very thin irregular veinlets and networks of fluorspar, which in the sandstones compose a "cementing'' bond for the rock fragments, is the rule. At some places, as for example at the Mary Belle mine, and at the Columbia (See U. S. Geol. Surv. Prof. Paper 36), sulphides, chiefly zinc blende, occur in and replace the limestone walls together with crystals of quartz. Much impregnation of the walls by zinc blende, especially between two fissures, is also reported at the Big Four mine, the workings of which were inaccessible for examination.

Vein Structures.

The lack of prominent crustification in the veins has been remarked and needs only to be emphasized here. A rough banding is frequently developed by the metasomatic penetration of fluorspar along wall contacts of calcite in some places and in other places by a more or less centrally situated replacement.

A more definite sheeting structure is noted where nearly parallel closely spaced ''slip'' planes were formed subsequent to the deposition of fluorspar and along which, in some cases, sulphides—especially galena—were deposited. Also to be mentioned are cases where late faulting in the vein matter has brought fluorspar filling into juxtaposition with a calcite-fluorspar mixture, the two portions being sharply differentiated by the shear plane.

Vugs are not rare, but are small, usually measuring only a few inches in greatest dimensions. No particular alignment of vugs centrally in the vein filling appears, nor are the individual cavities particularly elongated parallel to the general vein direction. Vugs usually contain well-formed scaleonohedrons of calcite, which are a late generation of this mineral, and less commonly cubes of fluorite with or without superimposed calcite or sulphide crystals.

Cavities in the Wall Rocks.

Quite frequently where the wall rocks consist of limestone, particularly of the St. Louis-Ste. Genevieve horizons, downward percolating waters of meteoric origin have effected solution of the wall rock and calcite of the veins forming cavities close to and sometimes extending into the vein matter. Such cavities in many cases have become partially or wholly filled with clay and water, giving rise to the so-called "mud runs" when penetrated during mining operations. The clay in these cavities is partly the result of slow infiltration through channels reaching from the surface, and partly the residual insoluble material of the limestone wall rock, the soluble lime carbonate having been removed by the carbonated ground waters. The waters follow especially the contacts between vein matter and wall rock.

Wall Rock Inclusions.

Included fragments of limestone, shale, or sandstone are common at the borders of the veins. Inclusions in the central portions are remarkably few, especially in the fluorspar bodies associated with coarse calcite between limestone walls. On the other hand, marginal masses of calcite frequently contain small limestone fragments.

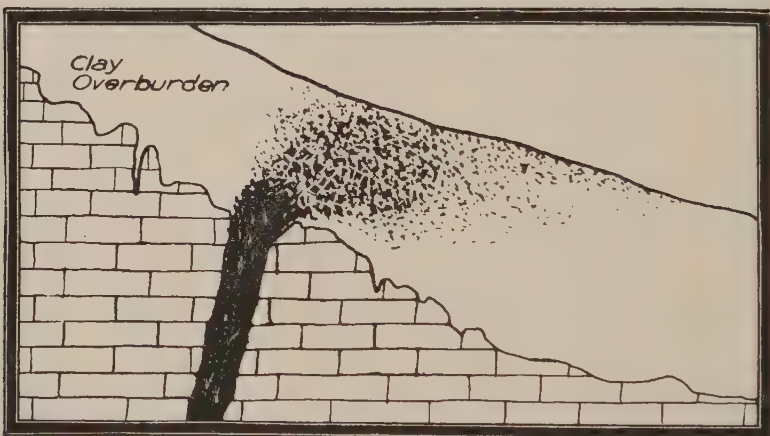
Superficial Deposits

A large amount of fluorspar is won from surface pits and trenches in the heavy clay residual mantle of limestone areas. In such clay overburden local concentrations of disintegrated "gravelly" fluorspar accumulate during the process of decomposition and removal of the limestone walls of veins. These deposits are locally called "gravel" deposits; in all cases, however, they are derived from fissure veins, are always indication of nearby vein material, and are purely of superficial character, being confined to the mantle clays above bed-rock.

During the attack of bed-rock limestone by waters of meteoric origin, the soluble constituent is removed leaving as residue the relatively insoluble clay. The clay almost invariably becomes red-colored through the oxidation of iron salts during the decomposition of the rock. Such clay mantle represents but a minor proportion of the original rock mass; the insoluble included vein matter thus becomes greatly concentrated unless washed away into stream courses by surface waters. Accordingly the workable deposits of "gravel" fluorspar are sometimes derived from veins of economic width, and sometimes from veins too narrow for exploitation. Hence the occurrence of a large "gravel" fluorspar bed does not necessarily indicate the presence below the clay mantle of a solid vein of economic size.

Where much mining of the superficial deposits has been carried on, the distribution of surface workings is frequently indicative, in a general way, of the position of a well-defined vein at the depth of solid rock walls. ''Gravel'' mining is usually the first stage in the development of mineral land. The importance of prospecting to solid walls before evaluating a property cannot be over-emphasized, for the reasons stated above.

Where ''gravel'' deposits occur on a hillside, the tendency of clay to creep slowly down-slope results in a more general dissemination and spreading out of the deposit; thus over an entire slope below the position of vein outcrop gravel spar may be



(10) Diagram illustrating relation of "gravel" deposit in residual clay on a hillside and its relation to original vein and to bed rock. Creep of deposit illustrated.

found. In such cases the ''gravel'' deposits assume a roughly tabular or blanket form, and present particular problems in mining. Gravel deposits may be thus eluvial, extending rather continuously fifty feet or more down-slope from the vein; they have never been concentrated as placer-like deposits, that is by entire removal from the region of the vein outcrop by surface streams and concentration elsewhere at places of lower gradient.

The matrix of the superficial deposits is chiefly the red clay of limestone decomposition, but is in part silicious with streaks of sand or with fragments and nodules of chert. The mined material is easily cleaned by washing, however, and frequently a high-grade product is obtained at little mining or milling cost.

Metallic minerals are conspicuously rare; in some cases unoxidized galena remains in the "ore"; usually the zinc has disappeared, having been changed over to zinc carbonate and removed in solution or remaining as coatings of earthy character easily removed during washing.

This type of deposit may be mined with little expense either initial or running, and the product very inexpensively milled; thus it is adapted to exploitation with little capital.

"Gravel" fluorspar as won from the superficial deposits should not be confused with the "gravel" product of mills. The latter is purely the result of milling, and the term as here applied is in no way indicative of the natural mode of occurrence of the material.

CHAPTER V.

PARAGENESIS AND ASSOCIATION OF MINERALS

General Remarks.

In this chapter are described and discussed in detail the structural relationships of the minerals and their significance as regards modes and relative times of deposition of the minerals.

The primary minerals—calcite, fluorspar, galena, sphalerite, chalcopyrite, and quartz—were deposited, apparently, during a general period of mineralization. While the precipitation of each was not necessarily sharply separated in time from the others, there seems, on the other hand, to have been no general development of all the minerals at the same time. Geologically, they may be considered as contemporaneous, but not completely simultaneous. A study of microscope sections of the ores and gangues correlated with large scale observations of the minerals in place suggest very strongly that a fairly definite and simple sequence in deposition occurred, a sequence which characterizes the veins of the entire Kentucky-Illinois fluorspar district. In this paragenetic scale, however, it appears unlikely indeed that the time of deposition of any one mineral was distinctly separated from the others, except in the case of part of the zinc blende. There was rather an overlapping of the periods, so that the entire mineralization of the deposits represents a single geologic event. There is as yet no reason to believe that the circulating waters from which the minerals were precipitated were subjected to abrupt changes in composition, or that they were qualitatively greatly variable over the area.

The structural and textural features of the veins point to two general processes by which the minerals were deposited, i. e., by precipitation from supersaturated solutions in more or less continuous open fissures and cavities, and by the metasomatic action of solutions upon previously deposited substances whereby an earlier mineral was partly dissolved and replaced by a later mineral through the simultaneous solution of the former and precipitation of the latter. The processes were greatly affected by the character of the walls. The one process, simple filling, argues the existence of open spaces and the presence of supersaturated solutions. The other mode, metasomatism, or replacement, requires that solutions be brought into contact with soluble solid matter as well as a supersaturated condition of the solution with respect to the newly precipitated mineral. Such supersaturation may indeed be caused in part by the dissolving of the soluble solid. Metasomatic changes are probably volume for volume.

Both modes of mineral deposition appear to have operated in the development of the fluorspar veins. In large parts of the deposits the vein filling was precipitated in open cavities and fractures, more especially so where the walls were non-calcareous. Sandstones, silicified to quartzite to a great extent, were extensively fractured during the period of general faulting and in the interstices of the breccia thus formed, as well as in the more persistent fracture planes of the fault zone, precipitation of fluorspar occurred without appreciable replacement of the wall-rock material. Limestone walls, on the other hand, are usually seamed with calcite veinlets and calcite also frequently constitutes a large proportion of the vein filling in these horizons. It is in such places that the phenomenon of replacement is strongly developed, though it was accompanied by considerable precipitation without replacement. Indeed, it appears that in places one of these modes was predominant; in other places, the other mode was more pronounced. It would be difficult to attribute to replacement the major role in the formation of the veins; it would be equally difficult to consider it unimportant. In the Illinois mines, where more extensive mining has been carried on, particularly with reference to depth, the phenomena of replacement of limestone by calcite, and of both of these by fluorspar are so marked as to lead one to the belief that the process was responsible for the development of many of the larger masses of fluorspar, in which case the process becomes of basic importance economically. So far as yet discovered, the Kentucky veins appear entirely similar in structure, mineral association, and paragenetic sequence to the veins of the Illinois field. More intensive and deeper development of the chief Kentucky deposits must be awaited before the degree of importance of the replacement process can be established. The present facts are, however, highly suggestive. While it seems probable that the full importance of replacement has not been appreciated in the past, nevertheless the recognition of the phenomenon is not entirely new. In 1892, Emmons stated[1] that "the relation of the crystalline calcspar to the fluorspar suggests that the latter may have been formed as a replacement of the former"; and again, "A considerable portion of the deposit, especially in the hanging wall portion of the vein,[2] has undoubtedly been formed by replacement." Bain mentions the "general fact of the replacement of calcite by fluorite."[3] On the other hand, W. S. T. Smith, writing on the Kentucky deposits,[4] while noticing occasional replacements of limestone, and even of quartzite, by fluorspar and other minerals, attaches no particular importance to the phenomenon, and believes that the deposits originated as fissure fillings without much metasomatic action. In an investigation of the Illinois veins[5] the present writer was impressed by the strong replacement structures seen everywhere in the solid vein matter underground, and later close study of specimens and microscope sections disclosed abundantly the replacement relationships existing between limestone and calcite as replaced materials, and fluorspar, galena, zinc blende, and quartz as replacing minerals. The replacement of fluorspar by sulphides was also seen.

The structures and textures of the Kentucky veins appear, so far as now disclosed, in all respects similar to those of the Illinois district. The Kentucky field is areally greater, but the mining operations have in most cases not been carried much below the thick surface clay mantle, so that the effects of ground waters of atmospheric origin are always present, and in most cases have appreciably modified the original structures of the veins. The most pronounced effects are, of course, the dissolution of the calcareous wall and vein materials, and the carbonation of the metallic minerals, effects which destroy such replace-

[1] S. F. Emmons: Transactions Am. Inst. of Mining Engrs., XXI, p. 51.

[2] Speaking of the Rosiclare vein.

[3] H. F. Bain: U. S. Geol. Surv., Bulletin 255, p. 40.

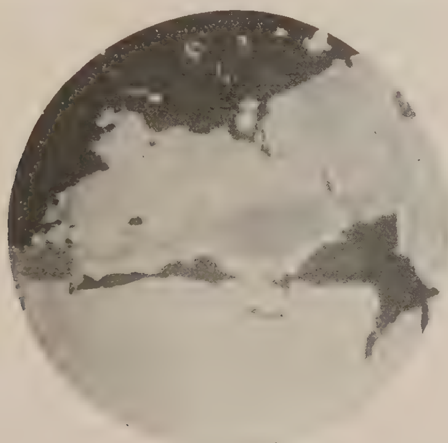
[4] U. S. Geol. Surv., Professional Paper 36, 1905.

[5] Weller, S., and others; The Geology of Hardin County; Illinois State Geological Survey, Bulletin 41, 1920.

ment features as were originally present or prevent their recognition as such. In mines where undecomposed wall-rocks and vein matter are reached in the mining operations, such as exist, for example, at the Mary Belle, Franklin, Holly, Haffaw, Bonanza, and Tabb mines, the replacement features are to be seen. At these mines one or both walls are of limestone and the vein fillings contain variable proportions of calcite. At the Lucile mine the walls are chiefly argillaceous and quartzitic at the present depths, calcite is very minor in amount, and the chief mode of deposition seems to have been by precipitation without replacement. Concerning replacement features as general and characteristic phenomena, and their importance in the development of large mineral bodies, much is to be learned and inferred from the large and more extensively worked veins at Rosiclare. The veins are not typical replacement veins, however, since a great deal of the vein matter was deposited, apparently, in open spaces, and since replacement structures are rather closely confined to the relatively narrow fault zone. The lenticular forms of some of the "ore" bodies, some of which reach dimensions of thirty to forty feet in width in Illinois, are believed to be due in large part to the replacement of calcite and limestone by fluorspar.

Calcite and Fluorspar.

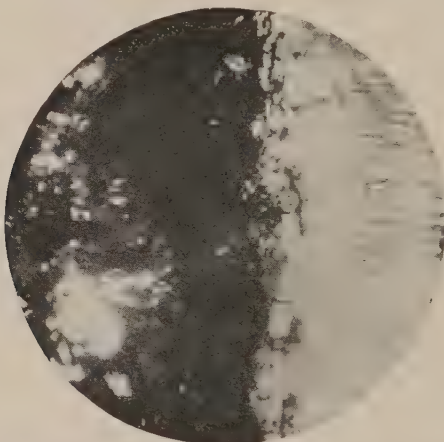
In the sequence of events during the formation of the veins calcite appears to have been the first mineral developed. Subsequently, during the periods of deposition of the fluorspar, galena, zinc blende, and quartz, the calcite was partly replaced by these minerals. The replacement patterns thus developed display consistent metasomatic structures and textures. Rhombohedrons of calcite are very numerous in parts of the fluorspar masses, spotting a vein face irregularly with these included mineral masses, whose rhombic outlines are very often more or less well-rounded, as though by some process of corrosion. Replacing patches of fluorspar frequently follow the cleavage and twinning directions of calcite, as well as indefinite directions, so that, while replacement proceeded in all directions, the calcite crystallographic directions often partly controlled the penetration of the fluorspar. In the masses of fluorspar such rhombs of calcite, penetrated with fluorspar veinlets which often follow crystallographic directions for part of their courses, appear completely suspended. In some places the included calcite makes up the major portion of the vein material; in other places it is minor in amount, no regularity in its distribution being apparent. In microscope sections the conformation in places between calcite twinning and cleavage directions, and the penetrating fluorspar is impressive. Frequently also small areas of calcite, entirely surrounded by fluorspar, show exactly similar orientation under the microscope, indicating their original exist-



(11) Fluorspar (black) widening along contacts of calcite grains and penetrating calcite (light). Photomicrograph of vein specimen. (x12).

ence as a single calcite rhomb. In such groups of included patches not only do the calcite areas reach extinction between crossed nicols simultaneously but there is also conformity in twinning phenomena. Included patches of calcite in fluorspar are abundant.

The distribution of the two minerals in the veins is entirely consistent with the conception of replacement of calcite. Uniform banding is absent except where it consists of the ribbon structure that is due to shearing movements which developed a series of closely spaced parallel planes of fracture along which, in many cases, later precipitation of sulphides occurred. Crustification, or "comb structure," is absent as a vein structural feature; it may be found in small open cavities within the veins, but has no definite relation to the wall rocks. In places calcite lines the vein walls, forming the border of the vein. These calcite bodies show great variation in width, and their contacts with the fluorspar masses are sinuous to a high degree in places where slip planes do not separate the two minerals. Occasionally indeed the fluorspar seems to be molded against a slickensided surface of calcite. Large masses of calcite may also occupy relatively central positions in the veins, being bordered on both sides by fluorspar. This feature is likewise con-



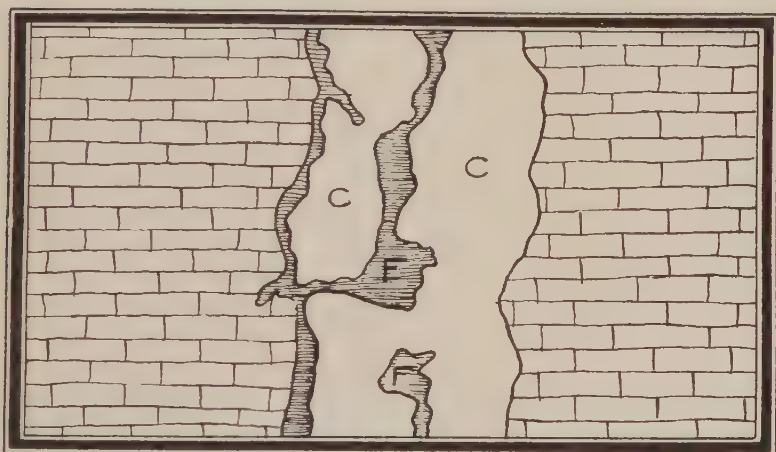
(12) Photomicrograph x30. Thin section of vein specimen showing a characteristic type of contact between calcite (light) and fluorspar (black). Nicols crossed. Replacement of calcite by fluorspar.

sistent with the idea of replacement of calcite; replacing minerals are characteristically deposited along contacts, which furnished minute, but nevertheless active and persistent, channels of access for the replacing solutions, thus isolating extensive patches of the previously existent mineral. The contacts of the two minerals in such cases are irregular.

It is believed, therefore, on the basis of the structural relationships existing between calcite and fluorspar in the veins, that fluorspar deposition took place, not only abundantly in open spaces, but also to a large extent by the replacement of calcite where large masses of this mineral had developed as a fracture-filling material, and that by such a process were some of the larger "ore" bodies, or lenses, developed.

Calcite and Wall-Rocks.

The limestone walls, especially along the major veins, usually show considerable fracturing. These fractures are commonly filled with coarse-grained calcite similar in its character to the calcite of the main veins. The small fractures of these border zones, while found in trends of all directions, are more particularly occupying positions of general parallelism with the main fracture zone, and apparently are concomitant effects of the main period of faulting in the region. That this general faulting of the region was marked by pronounced shattering and



(13) Section of a vein showing replacement relation of fluorspar, (F) to calcite, (C). A type of structure that may be found in any vein. From Bonanza Mine, Lola district.

shearing of the walls along the major fault courses is obvious underground, especially along the cross-cuts leading from shaft stations to the drifts. Where the walls consist of limestone this phenomenon of calcite veinlets is prominently displayed, but in wall-rocks of other types the veinlets are few or wanting.

Occasionally the main vein filling consists entirely of coarse calcite with included fragments of limestone and other wall-rock materials.

Close to the main zone of mineralization, fluorspar may be found as a frequent constituent of the border veinlets, but away from the veins its occurrence in these veinlets is increasingly rare, as a rule, so that much of the calcite of the border zones may be free of fluorspar, while within the main zone fluorspar may be present in economic quantities.

The width of the border veinlets is greatly variable. It is usually from a fraction of an inch to three inches, except in the few feet immediately bordering the main fault plane.

It appears likely that the calcite was formed by the recrystallization of wall-rock material, as well as by its possible introduction through the agency of circulating waters. Thus there appears to be a direct genetic relationship between the vein calcite and limestone walls, the breccia of the latter providing the material.

Fluorspar and Wall-Rocks.

Fluorspar veinlets and masses are found between and within all types of wall-rocks along the fracture zones. As a rule the mineral is more closely confined to the immediate vicinity of the main fracture than is calcite.

Workable bodies of fluorspar have been mined between walls of all types, but limestone horizons were more favorable for deposition of the larger ore bodies. Thus, at the Mary Belle mine, for example, walls of limestone prevail, while at the Lucile mine fluorspar has been mined successfully between walls consisting mostly, at least in the upper levels, of shales and sandstones (now quartzitized). In the Franklin mine fluorspar concentration increases markedly with depth toward the limestone wall material of the lower level although the mineral is present in variable amounts in the upper levels where shales and sandstone predominate.

In limestone walls replacement veinlets and patches of fluorspar penetrate the wall irregularly, except in those portions where marked slickensided surface and gouge seam forms the contact between vein and rock. It appears that fluorspar has readily replaced limestone where the latter has not been protected by an impermeable "gougy" coating. In mining, the fluorspar masses easily break away from the slickensided wall contacts.

In walls of sandstone (usually "quartzite" in the immediate vicinity of the veins), fluorspar has been precipitated as very narrow veinlets filling the small fractures of the wall breccia but the mineral apparently shows but slight replacement relationship toward the wall material. There are indeed suggestions of quartzite replacement to be found in some microscope slides, but the feature is not positively identified, and is certainly not prominent. While it is not unreasonable to expect that some replacement of the rock took place, it is on the other hand certain that the process was of slight development and without economic importance, as it did not assist materially in the development of large mineral bodies.

Sandstone walls in the region are usually greatly shattered without the development of gougy material along the walls so that very small amounts of fluorspar appear distributed in such rocks as a deposition from mineralizing waters which found paths of lateral circulation in the small fractures of the walls. Small veinlets thus wind irregularly through such walls and serve as a cementing bond for the breccia. The mineral is never accumulated in large amounts in these positions, although its presence is to be noted in the quartzites at some distances from the veins.

In shale walls, as in the sandstones, replacement phenomena are to be seen microscopically, but the process was inadequate for the development of large mineral bodies. The fluorspar here occurs in narrow, winding veinlets, sometimes with associated calcite, frequently alone. It is usually a strongly colored variety of spar that is thus situated, rather than the white, yellowish, or brownish types found in the workable veins. The original fissures between shale walls appear to have been less open than in those places where other wall rocks prevailed; the shale material apparently was only slightly susceptible to chemical processes of the replacement type, and the workable veins accordingly became poorer or unworkable in the shale horizons. Inasmuch as shale formations are chiefly found in the Chester series, alternating with usually thin limestones and relatively thicker sandstones, these stratigraphic positions are less favorable for prospective mines than where one or both walls consist of the Ste. Genevieve or St. Louis formations.

Under the microscope narrow veinlets of fluorspar in shale frequently show suspended and corroded fragments of the rock. The replacement feature has not been seen in megascopic proportions.

Metallic Sulphides.

The chief sulphide minerals of the district are zinc blende (sphalerite) and galena. The other sulphides previously mentioned as vein minerals of the district are present only in very minor amounts and occur as small scattered and occasional grains with the sulphides of lead and zinc.

In their structural and paragenetic relationships most of the zinc blende and the galena are similar, in that they are both subsequent to calcite and fluorspar in their deposition, and to some degree replace these latter minerals. Developed impressively along fractures and cleavages in these minerals the sulphides thus occur in irregular bands or veinlets, which frequently widen into "pockets." Persistent shear planes of more or less definite trend also contain these metallic minerals, so that the "ore" as mined may consist of a banded development of metalliferous and non-metalliferous portions. The "center slips" of the veins are often found to be thus mineralized. These shears are probably the principal loci of the vein sulphides, so that, the shearing having taken place subsequently to the deposition of the calcite and fluorspar, the contained sulphide minerals are likewise of subsequent development. Closely spaced parallel shears in fluorspar bodies, producing the "ribbon structure," are prominently mineralized in some places. Winding indefinitely along the cleavage planes and fractures of both fluorspar and calcite very thin veinlets of the sulphides fill the cracks and partially replace the host minerals, occurring in partially idiomorphic grains, so that while, in these cases, the sulphides are definitely situated along fractures or along contacts between fluorspar or calcite grains, they characteristically widen out slightly into the surrounding antecedent mineral. The feature is to be seen both in hand specimens and in microscope sections, the latter best showing the replacement features. Replacement of fluorspar and calcite by the sulphides is never so prominent as to have allowed the development of very large sulphide bodies by this process alone, but the phenomenon probably expressed itself in places by the deposition of some of the "pockets." By far, the chief controlling factor seems to have been the existence of the shear planes and fractures.

Under the microscope the metallic sulphides plainly occupy areas of fracture, with positions along minute fractures either as very narrow veinlets—occasionally widening into larger irregular patches—or as isolated grains. Crystals are occasionally found within fluorspar grains in situations suggestive rather of their deposition during the period of fluorspar precipitation. The isolated grains are usually crystalline in form. Although frequently dispersed along minute fractures which allowed the ingression of depositing solutions, they extend into the surrounding fluorspar or calcite areas by reason of having replaced these minerals.

Thus it appears that the sulphides were precipitated during a period overlapping and immediately following the period of fluorspar deposition, since they appear entirely inclosed to a small degree, and follow fractures to a large degree.

Among the sulphides no definite order of deposition could be established. Occurring together in the veins with similar positions, they mutually inclose each other, and show no consistent intersecting phenomena which would allow the interpretation of a definite succession. Beyond the facts then that they are chiefly subsequent to, and partly replace both calcite and fluorspar, no further statements of paragenesis may be made at present. Chalcopyrite and pyrite, more than the other sulphides, seem to show a greater degree of contemporaneity with the fluorspar, but the occurrences of these sulphides are also to be noted in positions of subsequent development in association with the lead and zinc sulphides. Crystals of fluorspar are also found completely inclosing chalcopyrite and pyrite in positions not related to fractures, in which cases these sulphides must have been precipitated before or during the precipitation of the inclosing mineral.

The major veins show great variability with respect to their sulphide contents. In some of the vein systems, for example, the system on which the Columbia mine workings (abandoned) are situated, some parts may carry considerable sphalerite with very little or no galena, while other parts may be pronouncedly lead-bearing with little or no sphalerite. Thus certain mines are characterized by the presence of zinc, others by the presence of lead, while most commonly where sulphides are present both sphalerite and galena are found. Locally, large pockets of the sulphides, separately or together, have been developed. Galena, more than zinc blende, seems to have such a tendency, while the latter shows a greater tendency to fill small fractures in vein matter, and to be the distinguishing sulphide feature of certain of the major vein systems.

A few veins contain no sulphides at all in the portions opened so far.

Quartz.

The quartz found in the veins is mostly of microscopic size, and is occasionally of such pronounced development as to seriously affect the value of the deposit.

Microscopic examinations of thin sections of vein specimens from numerous mines indicate an introduction of quartz accompanying the sulphide mineralization period. In these cases the mineral is distinctly subsequent to the fluorspar, and may also be in part subsequent to the metallic minerals. Sections showing sulphides in fluorspar usually display a variable amount of minute, but well-crystallized grains of quartz in the fractures that also carry the metals. The photomicrographs (Figs. 7 and 8) show the character and disposition of such vein quartz. The mineral replaces both calcite and fluorspar, to the detriment of the latter, for its abundance along some fractures gives locally a high silica content to the "ore," while the small sizes and scattered distribution of the grains forbids any possible separation of the minerals by milling. Fractured fluorspar, apparently of good quality, may, upon analysis, show an unexpected high percentage of silica. In the thin sections examined these minute quartz crystals accompany zinc blende more persistently than galena, and galena-bearing fluorspar frequently shows little or no quartz. This condition of mineral association should be carefully investigated by operators in the opening up of new or of abandoned fluorspar properties. Some of the high grade fluorspar veins of the district carry the lead mineral in places without associated zinc sulphide. While the zinc blende may be separated by milling operations, the quartz content is not necessarily much reduced in the operation, inasmuch as the two minerals, although associated in the same fractures of the fluorspar, may not be greatly intergrown. Frequently the quartz microcrystals are seen to be dispersed through the fluorspar areas bordering the fracture in which the zinc blende grains are more closely confined. The quartz individuals are very much smaller in size, on the average, than the sulphide grains.

CHAPTER VI.

ORIGIN OF THE DEPOSITS

Lead-Zinc Deposits of the Mississippi Valley.

Several localities in the Mississippi drainage area are noted for the production of lead and zinc ores. Chief among them are the Missouri deposits, from which the country derives a very large part of its supply of these two metals. Southwestern Wisconsin and the adjoining part of Illinois, too, have long been producing these ores, but this district plays a very subordinate role in the total annual production for the country. In the Joplin, Missouri, district the evidence relating to the genesis of the deposits points very strongly toward their deposition from circulating artesian waters which obtained their metallic contents from a wide area of Cambrian and Ordovician rocks in which the lead and zinc values were presumably disseminated.[1]

The origin of the southeastern Missouri lead deposits appears to be less definitely established, but the prevailing opinion attributes their deposition also to cool meteoric waters, and does not in any manner connect this concentration directly with igneous activity. It is of interest to note, however, that L. V. Pirsson suggested the possibility of slowly ascending volatile substances from an igneous source. Some of the writers have considered the deposition from thermal waters ascending along deeply extending fissures. Considering first the geologic condition and the character of the ores, it would seem that promoters of an hypothesis which attempts to derive the ores from magmatic sources must bear the burden of difficult proof.

The character and structure of the zinc-lead ores of the southwestern Wisconsin-northwestern Illinois deposits indicate a meteoric origin also for these ores, according to U. S. Grant,[2] who describes relations between the ores and structural basins into which an impervious stratum appears to have caused the metalliferous solution to circulate. The ores are represented as

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[1] C. E. Siebenthal; Origin of the Zinc and Lead Deposits of the Joplin Region, Missouri, Kansas and Oklahoma; U. S. G. S. Bulletin 606. (Herein is reviewed a mass of evidence which culminates in a convincing argument for the mode of origin promulgated.)

[2] Wisconsin Geological and Natural History Survey, Bulletin 14, 1906.

of very shallow depth, and confined to the horizons at or above the impervious "oil" shale.

The Mississippi Valley ore deposits mentioned above are not of the fissure vein type, but rather consist of gash veins, cavernous deposits, and bedding replacements, in definite horizons. The dimensions of distribution are more pronouncedly horizontal than vertical, in this structural feature presenting a decided contrast with the Kentucky-Illinois fluorspar-lead-zinc veins. Siebenthal states: "The Joplin district is characterized by the absence of well-defined fissures, and by the common occurrence of the ores in large elongate bodies of generally slight horizontal extent, known as 'runs,' or in comparatively thin tabular bodies of great horizontal extent, known as 'blanket breccias' or 'sheet ground.'" The southeastern Missouri district is lead producing, rather than zinc producing, and here the ores are of the disseminated type, occurring largely in structural troughs.[3]

Some concentration occurs along fault planes, but mostly the ores have more pronounced horizontal distribution in dolomite and shale horizons, in part filling or lining joint planes or cavities. The deposits of the Wisconsin-Illinois-Iowa district furnish both zinc and lead, chiefly in so-called "gash" veins, flats, and pitches, all of which are structurally discontinuous and short as compared with true fissure vein ore bodies.

The lead of all these regions is notably lacking in silver, and the ores are commonly termed non-argentiferous. Fluorspar is absent. Barite is said to be present, but subordinate, in the Missouri ores. Calcite is a prominent gangue mineral in all the deposits, while iron sulphides are present in considerable amounts, chiefly as the mineral marcasite.

Finally, igneous rocks as a pronounced and distributed structural feature, are absent.

The Fluorspar-Lead-Zinc District.

The fluorspar veins of western Kentucky and southern Illinois therefore present several vitally important contrasting features throughout as compared with the above-mentioned regions.

[3] For a brief general description of this district and for bibliography see H. Ries; Economic Geology; Wiley & Sons, New York, 1916.

Normal faulting is very pronounced, complicated, and well distributed in the producing districts. The fault fissures practically entirely determine the position of ore concentration. The ore deposits are therefore fissure-veins and never gash veins, disseminations, "sheet" ground, or cavernous deposits, though horizontal replacements of limestone occur in Illinois to a minor degree.[4] They have been reported in the Kentucky area,[5] but not yet seen there by the writer.

In mineral association the fluorspar veins are markedly different from the other lead-zinc regions. Fluorspar and calcite are the dominant vein minerals, while the galena is distinctly silver-bearing. The sequence of gangue and ore minerals is definite and uniform, with strong replacement features commonly displayed between certain minerals. Finally, wall-rock alteration, though not of completely original development is pronounced locally; taking the form of the jasperoidization of limestone in a few, and the "quartzitization" of sandstones in many cases.

Finally, the presence of numerous igneous rock bodies—chiefly dikes—composed of extremely basic differentiates of an hypothetical parent-magma at an unknown depth gives petrologic distinction to the entire Kentucky-Illinois fluorspar district.

The points of contrast between these two types of lead-zinc regions possess great significance, inasmuch as they are the structural, textural and mineralogical features that are of first-order importance in the formation of many known ore deposits. It would appear reasonable accordingly to look for other and more probable explanations as to origin than those commonly ascribed to the zinc-lead deposits of the Missouri district or the upper Mississippi Valley district.

Views of Previous Writers.

The Illinois deposits were very briefly examined in 1891 by S. F. Emmons,[6] at which time a very few mines and prospects were accessible, chiefly in and near Rosiclare. At that time igneous rocks were unknown in the district (the first Illinois

[4] See Illinois State Geological Survey, Bulletin 41.
[5] F. Julius Fohs: Econ. Geol., Vol. 1910, p. 382.
[6] Emmons, S. F., Fluorspar Deposits of southern Illinois: Am. Inst. Min. Eng., Vol. 21, 1892, p. 52.

discovery being made in 1902), although a single dike had previously (1889) been discovered in the Kentucky district, some ten miles distant. Mr. Emmons attributed the formation of the fluorspar veins to the action of circulating ground waters, which were supposed to have leached the fluorspar content from the limestones of the district, and to have then issued into the fissure when the mineral was precipitated. This theory, the writer feels, is not now acceptable in the light of the large amount of data accumulated in late years, and in the light of recent progress in the study of ore genesis and mineral relationships. It seems difficult to attribute to circulating ground water in a limestone region the ability to dissolve minute quantities of fluorspar from a broadly distributed terrane and to later deposit the fluorspar in relatively much localized and more or less open fissures. It is to be recalled, in this connection, that in reality only a minority of fissures are mineralized, and moreover that the filled fissures are, except in the immediate vicinity of the veins, pronounced fault fissures and not single joints. This contrasts, as stated earlier, with the types of ore-bodies of the Missouri and upper Mississippi Valley deposits. It is very interesting to note here that Mr. Emmons suggested the strong replacement features of the veins at Rosiclare, placing fluorspar subsequent in time deposition to calcite, with replacement of the latter by the former.

An investigation was begun in 1888 by Dr. E. O. Ulrich under the auspices of the State Survey, and a brief report issued in the Crittenden Press of Marion, Ky., in 1890.[7] In the field season of 1902, Dr. Ulrich and Dr. W. S. T. Smith made further study of the district, the report of which appeared in the cited Professional Paper 36. In this publication Smith supports the theory that the fluorspar and metallic minerals were leached from the deeper-lying limestones and were deposited in the upper zones of fissure, stating, however, that "it is not impossible that its source may have been the magma from which the peridotite dikes were derived." Smith cites three analyses to show that the regional limestones contain appreciably more than a trace of fluorine, and one analysis from the Joplin, Mo., district in

[7] Op. Cit., p. 19.

which no fluorine appears. It would seem, however, that many analyses of limestone from widely scattered areas would be necessary to argue this point, especially in view of the fact that minute quantities of fluorine are generally reported to be present in sediments of all kinds. Furthermore, it might be argued that the small amount distributed in the rocks of the fluorspar area was precipitated by the same waters that were responsible for the more notable vein concentration, or even by ground waters that were responsible for the more notable vein concentration, or even by ground waters circulating subsequently to the formation of the veins.

If fluorspar is indeed a common mineral of sedimentary formations, especially limestone and dolomite, as we are led to believe,[8] we might expect that fluorspar veins would be of very common occurrence in limestone terranes. This does not appear to be the case. It is certainly true, on the other hand, that some occurrences have been reported in regions where igneous activity and rising thermal waters cannot be postulated on the basis of any known facts. In the central Kentucky district, for example, a few narrow veins of commercial importance fill joint fractures in the limestone formation, while there appears no evidence, even remote, for supposing that any form of igneous activity is directly responsible for these depositions. The mineral association in this district is only in part similar to that of the field under discussion. Again, Bagg[9] describes an occurrence in Wisconsin of joint seams in Ordovician limestones in which the mineral is associated with calcite and galena; the fluorspar appears to be confined to a rather thin stratum. The origin is not attributed to igneous activity at depth partly because of its limited horizon and partly because no igneous rocks are known to outcrop, though granite is supposed to be present at a depth of about 700 feet. The few exceptions to the occurrence of fluorspar where magmatic forces cannot reasonably be hypothecated seems to more forcibly call attention to the general lack of concentration of the mineral by artesian or other ground waters, even though the element fluorine has widespread litho-

[8] See F. W. Clarke, Date of Geochemistry, U. S. G. S. Bulletin 695, p. 555.
[9] Bagg, Rufus Martin, Fluorspar in the Ordovician Limestones of Wisconsin; Bulletin of the Geol. Soc. of America, Vol. 29, pp. 393-398.

logic distribution. The geographic limitation, vertical extent, and controlling regional structure, absence of mineralization in many of the faults, and unusually large concentration of fluorspar in others, would seemingly be rather opposed to deposition from general ground or artesian waters, and to favor an origin by forces which operated comparatively rapidly and locally, rather than through a long period of time.

While Ulrich and Smith were studying in the Kentucky field, H. Foster Bain was making a general economic survey of the Illinois field, lying chiefly in Hardin County, just across the Ohio River from Crittenden and Livingston counties of Kentucky. In his report [10] Bain states "that the evidence points to heated waters having been the agency by which the ores were segregated and that they obtained an essential portion of their load from a large mass of lower-lying intruded rock of which the dikes are now offshoots." While he does not state with finality a belief in the magmatic origin of the depositing waters, he favors the view that the fluorine at least is of direct magmatic origin, and looks with disfavor upon the view that disseminated fluorite in the limestone was the source of the mineral from the veins. Bain finds great genetic significance in the association of minerals and the "marked silicification of the hanging walls." He also states that the replacement of calcite by fluorite is a "general fact." F. Julius Fohs[11] "places the deposits in the thermoaqueous" class, and considers the interaction of metallic silicofluorides with calcium bicarbonate to be responsible for the deposition of calcium fluoride. He suggests a parent magma of which the dikes are apophyses as the likely source of the fluorine. The metallic sulphide minerals were precipitated through the agency of hydrogen sulphides, probably from the organic matter in the sediments, according to his view. Thus he ascribes a direct igneous origin for the fluorite and metallic sulphides.

In his study of the Joplin ores, C. E. Siebenthal [12] briefly

[10] Bain, H. F., The fluorspar deposits of southern Illinois: U. S. Geol. Surv. Bulletin 255, 1905.

[11] Fohs, F. J., Fluorspar deposits of Kentucky: Kentucky Geological Survey, Bull., 1907. The fluorspar, lead and zinc deposits of western Kentucky: Econ. Geol., Vol. V, pp. 377-386, 1910.

[12] Siebenthal, C. E. Origin of the zinc and lead deposits of the Joplin region, Missouri, Kansas, and Oklahoma: U. S. Geol. Survey Bull. 606, 1915.

discusses the deposits elsewhere in the Mississippi Valley, and, alluding to the Kentucky-Illinois district, calls attention to structural features favoring an origin similar to the Joplin ores. It would seem equally important, if not more so, to call attention to the marked structural contrasts between the districts, inasmuch as the most impressive structural features of the Kentucky-Illinois district are those most commonly associated with ore-bodies deposited by processes of decidedly different type than the processes which appear to have formed the Missouri ores. In six important particulars, the two districts are greatly different: the profound normal faulting of the fluorspar belt; the presence of numerous igneous rock bodies of a type suggestive of strong differentiation of an original magma; the unusual concentration of calcium fluorite (the mineral is apparently and entirely lacking in the Missouri deposits); the argentiferous quality of the Kentucky-Illinois galena; the silicification of vein walls: and the absence of "sheet ground," gash veins, and cavernous deposits in the fluorspar areas, unless indeed the "bedding" replacements of limestone in the Lead Hill section of the Illinois field are to be considered as an approach to the Missouri type of structures.

Probable Origin of the Deposits

In a report on the Illinois fluorspar deposits [13] the writer expressed a belief that the structures, mineral associations, and textural features of the ore-bodies strongly suggest an origin directly related to igneous activity at depth as opposed to a concentration effected by waters circulating through and abstracting their mineral contents from, the regional limestones far or near. The brief general study of the Kentucky deposits has in no important particular disclosed facts that would modify this view. Thus the writer is in general accord with the ideas expressed earlier by Bain and Fohs. He feels, however, that chemical influences of limestone and vein calcite upon the deposition of fluorspar from fluoriferous solutions, as well as the importance of the replacement mode of development of part, at least, of the fluorspar, have not heretofore been given sufficient prominence.

[13] Illinois State Geological Survey, Bulletin 41, pp. 247-304.

Until such time as more extended exploitation will disclose decisive facts concerning the origin, no positive statement that the vein materials are derivatives of a differentiated magma can be made. The position now taken is that the peculiar and localized conditions, structural and mineralogical, together with the evidence of igneous activity and of possible magmatic differentiates in the district point strongly in the direction of the igenous theory. It is necessary to theorize rather broadly, consider possible sources of the vein stuffs, and make comparisons with deposits of known igneous affiliations, as well as with those of purely non-igneous origin, such as the before-mentioned Missouri deposits. Indeed, analogy is by no means a small consideration, and very properly becomes a part of logical deductive reasoning; on the other hand, its limitations are to be clearly recognized.

Structural Relations of Fluorspar Bodies to the Dikes.

At the Perrigen Springs prospect, newly-opened, a fluorspar vein nearly two feet in width was found to have for one of its walls a slightly narrower peridotite dike, much decomposed, but clearly recognized. No veinlets were discovered penetrating the dike, nor does the rock appear to contain any fluorspar. A similar situation may exist at the dike prospect east of Levias, though here the only indication appears in the presence of marbleized limestone, peridotite, and vein materials in the waste pile of the abandoned prospect. In Illinois the Orr's Landing lamprophyre dike forms one wall of a very narrow vein of calcite, fluorspar, and sulphides. Veinlets also penetrate and cross the dike. Aside from these occurrences there are no instances of structural connections between igneous rocks and veins. These cases obviously offer no proof of consanguinity, inasmuch as the contact planes of dikes may conceivably offer narrow fissures easily followed by circulating waters, and therefore may be the natural position for some mineral deposition. These instances serve, however, to show the time relationships, namely, that dike intrusion preceded mineralization.

General Geologic Occurrence of Fluorine.

In granites and other acidic igneous rocks fluorite is found occasionally as a minor accessory mineral. The mineral is prominent in some pegmatite veins, as, for example, those of the Rockport, Mass., granite batholith.

The mineral is therefore seen to be stable, through a wide range of environmental conditions, related to both plutonic and volcanic igneous rocks and emanations. It is chiefly given up by a cooling magma to the gases and thermal water arising therefrom and hence most commonly appears in veins from high to low temperature types.

Fluorite is also found in sedimentary rocks, but in these it does not have constitutional importance. Limestones especially carry a slight fluorite content, and while the proportion is generally minute, from a trace to a small fraction of one per cent, the mineral is apparently of widespread and rather general occurrence as a limestone constituent. It has also been noted in the cementing material of sandstone.[14]

Fluorine is one of the constitutional elements of the mineral apatite, except the rarer variety chlor-apatite. Apatite is of widespread occurrence in all varieties of rocks; it is chiefly, however, of igneous derivation, being a common, and occasionally an abundant mineral of both coarse and dense textured, acidic to basic types. While usually a minor accessory mineral in these rocks it sometimes appears in impressive quantity, as in some of the dike rocks of the Illinois and Kentucky fluorspar fields. Secondly, apatite is common in metamorphic crystalline rocks, when high pressures, temperatures, and probably active solutions have effected the metamorphism.

The element fluorine is also present in numerous other minerals of igneous derivation, especially the micas.

In spite of the world-wide presence of fluorine compounds in sedimentary rocks, notable concentrations of the mineral are rare, and so far appear to be recorded almost entirely in areas where there exist also manifestations of igneous activity.

Sources of Fluorine.

Fluorine and its compounds are known chiefly in connection with igneous phenomena and their rock derivatives. Fluorides and oxyfluorides appear in igneous emanations from volcanoes, crystallizing as sublimates near the vent. The ascend-

[14] F. W. Clarke; Data of Geochemistry; op. cit.

ing hot spring waters of volcanic districts of the sodium carbonate type frequently carry fluorine; the mineral fluorite sometimes occurs in sinters of these springs, but is "rarely if ever found in the sinters of meteoric waters."[15] Fluorite is also a very common gangue mineral of metallic veins found in volcanic regions, and undoubtedly in connection with igneous activity. The instances of this are too multitudinous to cite.[16]

Source of the Kentucky Vein Fluorspar.

It is believed that the fluorine for the precipitation of the Kentucky-Illinois fluorspar bodies is a derivative of a deep-lying igneous mass, whose presence is indicated by the peridotite and lamprophyric dikes and sills of western Kentucky and southern Illinois. That fluorine existed in the magmatic source of these rocks is probably well indicated by the presence in them of unusual quantities of apatite and mica.

Character of Original Magma.

It is quite unlikely indeed that the composition of the original magma is represented by the extreme basicity of the exposed peridotite and lamprophyric bodies. Probably a considerable degree of differentiation took place before the intrusion of the dikes and the later development of the veins. The fact of differentiation is supported by the occurrence of probable volcanic breccias in Illinois which are apparently of acidic character.[17] The original magma was therefore undoubtedly more nearly of intermediate composition than the known dikes and sills. Its probable composition cannot yet be stated within narrow limits. The magma may have contained an unusual percentage of constituents which during differentiation and cooling pass off as gases and aqueous solutions.

Crustal Disturbances.

If an hypothesis of igneous origin for the veins is valid, the sequence of crustal disturbances attending the intrusion, differentiation, cooling, and mineralization appear entirely analog-

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[15] W. Lindgren, Mineral Deposits, New York, 1919, p. 97.
[16] See especially W. Lindgren, op. cit., especially Chapters 24, 25, and 26.
[17] Illinois: State Geological Survey, Bulletin 41, 1920.

ous with many mining regions where igneous forces have undoubtedly been responsible for the deposition of ores. An excellent and illuminating summation of such examples is given by J. E. Spurr.[18] Briefly the sequence is: (1) an upwarping of overlying strata by intrusion with some fracturing and relatively little faulting; (2) intrusions (dikes and sills); (3) another period of fracturing, the faults being mostly of moderate displacements; (4) mineralization by ascending solutions during the last stage of consolidation of the magma; (5) more settling and faulting during the final shrinkage stages of the batholithic mass, continuing for a long time subsequent to the period of mineralization and consequently causing the fracturing and displacement of the veins as well as the formation of more profound faults which will be barren of mineral.

The fact that the faults are of the normal rather than the reverse type suggests as their cause uplift and settling due to igneous intrusion and cooling rather than orogenic forces.

Objections to a Non-Igneous Origin.

The chief objections to theories that support as the mode of origin deposition from ground waters—either general or artesian—of meteoric origin, and in which the fluorspar is presumed to have been dissolved from regional sedimentary rocks, are:

(1) The constant association of veins with faults, and not with caves and joints.

(2) The barrenness of many deeply extending fault fissures, suggesting a relatively short period of mineralization, and a more extended period of faulting.

(3) The argentiferous character of the galena.

(4) The constant association of calcite and fluorspar, minerals having a common ionic base, and differing greatly in solubility, rendering the collection of relatively insoluble calcium fluoride from limestone terranes and the later replacement of calcite by fluorspar inharmonious processes.

(5) The general rarity of fluorspar concentration in sedimentary areas where igneous activity is not in evidence.

[18] J. E. Spurr: Econ. Geol.; Vol. 11, 1916, p. 601.

(6) The analogous structural, textural, mineralogical features and sequence of events in their history, between these veins, and metallic veins elsewhere that are of known igneous affiliation.

Geologic History of the Veins.

The facts outlined in earlier chapters of this paper suggest a sequence of events in the western Kentucky field as follows:

The region, having been the site of quiet and long continued sedimentation, with occasional gradual slight uplifting and down sinking allowing intervening periods of normal erosion, was subjected in post Mississippian, probably post Pennsylvanian, times to a relatively short period of deep-seated magmatic intrusion with attendant up-bowing and fracturing of the strata. Whether or not this was an expression of general isostatic adjustment that closed the Paleozoic in eastern North America, or whether it belongs to a crustal adjustment of some later date, is not apparent. The fracturing of the overlying rocks was closely followed by the intrusion of peridotite and lamprophyre dikes and sills from the differentiated magma. At a slightly later time, due probably to the adjustment of the overlying crust to the shrinking magmatic mass during its cooling and solidification, more fractures developed as normal faults. Along the faults, particularly at limestone horizons which largely furnished the necessary material, coarsely crystalline calcite was deposited, partly to wholly filling the fault fissures. Locally the calcite masses became brecciated and sheared by continued movement along the fault planes. Into these fault planes, partly occupied by coarsely crystalline calcite, thermal fluoriferous solutions ascended, largely as the last phase and accumulation of magmatic activity, but also augmented by circulating ground waters. The fluorine is believed to have come wholly from the igneous body. The fluorine of the solutions probably started as hydrogen fluoride, which reacted with calcium carbonate of the lower limestone horizons to form calcium fluoride. As soon as this solution became of sufficient concentration calcium fluoride was precipitated, chiefly in those portions of the fault where limestone walls prevailed and calcite vein filling had already been formed. The fluorspar was deposited partly by replacing calcite and limestone and partly by simple precipitation. The replacement phenomenon resulted in the development of irregular "ore" bodies and a general lack of crustification. Shortly after the precipitation of fluorspar, more fracturing took place along the veins, and along the newly formed channels solutions ascended carrying the metallic sulphides which were deposited, partly with replacement of the previously formed vein minerals, and partly as filling along the open fractures. It is possible that the metallic solutions were first chiefly lead depositing, later becoming zinciferous. Deposition of silica accompanied that of the metallic sulphides, chiefly the zinc blende, but also occurred at other periods subsequent to the first deposition of calcite.

Subsequently faulting occurred, sheeting and offsetting some of the veins and developing more faults; along these planes slight movement has taken place through several geologic periods.

Prolonged weathering and erosion have brought the surface down to the zone of vein formation, exposing the deposits to discovery and exploitation.

Economic Bearing of the Theory of Origin.

On the basis of the theory outlined above, the faults may be considered as extending several thousand feet below the present surface. It is probable that fluorspar mineralization continues in the major faults to the horizon of the Chattanooga shales, about 1,400 feet below the top of the Ste. Genevieve series. In and below this shale horizon the faults may continue without mineral bodies, or the vein filling may change in mineralogic character, either qualitatively or quantitatively. It cannot be stated that metallic sulphides will increase in amount with depth, but this appears possible.

Prominent faults of great displacement that show no mineralization at the surface, where the thick limestone series appear in the footwall will offer no inducements for prospecting at depth.

Dikes are not necessarily favorable places for prospecting.

The greatest concentration of fluorspar may be expected in certain parts of the field which appear to be chief "centers" of mineralization, probably directly overlying the higher portions of the hypothetical deeply-seated batholith. The veins are expected to become leaner on the flanks of these "centers," so that the outlying portions of the field offer little promise for the discovery of thick and extensive veins, at least to depths of the order of the present major veins in the Marion-Sheridan, Salem, and Mexico-Claylick districts.

CHAPTER VII.

DEVELOPMENT

The greater portion of this chapter is devoted to notes on the location and general characteristics of each of the principal mines and prospects that were being exploited or opened during or near the period of the writer's visits to the field. In addition, reference will be made to some of the more noteworthy mines of the past, descriptions of which appear in the various publications already cited, and which are now represented only by abandoned surface plants and waste piles.

It is not the intention herein to express judgment on the relative merits of the properties beyond a few generalizations on the character and promise of different parts of the field. Such could not be done, even were it desirable, without much detailed investigation and mapping of a nature that was not possible in connection with this general survey of the district and industry. Inasmuch as detailed geologic study and mapping of the formations and faults is contemplated for the entire district, and in continuation of Dr. Weller's work on the Golconda quadrangle, much that would otherwise have been a part of this investigation is intentionally unattempted. Such mapping is essential in the close judgment of vein continuations, structural connections between various mines, and the like.

The entire field has been the scene of very general prospecting activity. Countlss test pits and shafts are distributed over the several counties involved, while relatively few have reached the stage of continued economic production. During the history of the Kentucky fluorspar industry prospectors and operators seem to have been more concerned with immediate production than the development of permanent deep mines. As a consequence, many of the properties, frequently by contract mining, have been hastily scratched at the surface for the easily won "gravel" spar. In many cases this has not been an unwarranted method, as a quantity of easily obtained mineral was frequently taken from the concentrated surface "gravels" of veins which would prove too narrow for deeper mining. The resources in such cases are very limited and quickly exhausted. In other instances, this method has been employed on more meritorious properties to meet a sudden demand for fluorspar; the exploitation led to no permanent mine openings, and the money invested had no permanent representation. Frequently the course of several years has resulted in the sinking of numerous shafts on the same property and very closely spaced, while the investment of the same aggregate amount of money in one or two permanent shafts would have realized considerably greater profit in the end. A very few mines have, however, been well-developed with permanence in view, and while deep-mining is totally absent from the district these few have been developed to depths sufficient to prove the merit of the deposit and the advisability of continued mining. Examples of this type are the Mary Belle, Franklin, Haffaw, and several other mines. It is this type of mine that at present essentially controls the major part of the fluorspar production both in Kentucky and in Illinois, although the mines and prospects of temporary character contribute very appreciably to production in the times of greatest market demands.

The result of general surface pitting and exploitation of "gravel deposits" has been the discovery of numerous small veins of little or no promise as permanent mining propositions. These properties have apparently changed hands many times with alternate periods of attempted exploitation and abandonment. Prospective buyers of fluorspar properties will do well in the future to examine the past history of these properties and to critically examine the solid vein conditions rather than the past production or the presence of the "gravel" material. Undoubtedly scores of the deposits which have brought some profit to the operators by "gravel" mining will prove valueless when developed to depths where solid walls are met.

The map, Plate I, indicates the general location of the prominent mines and prospects. It is impossible as well as unnecessary to include all the known prospect shafts and pits. The more important mines of past history whose exploitation was notable are included. The geographic distribution of mines and igneous rocks is indicated, but without any attempt to delineate fault and vein courses, the purpose of the map being solely that of orientation. For convenience the entire field is arbitrarily divided into districts. In the absence of the determination of fault belts that will be brought out by the projected mapping, the present division is largely geographical. Although, as Ulrich's map indicates, and the contemplated map will disclose, some of the fault zones are of great extent and are exploited in more than one of these divisional districts; at present, nevertheless, the field lends itself better to this general discussion by resorting to the treatment hereafter followed, than by taking up the individual fault systems, some of which may be ten to twenty miles long, and are none too well traced at present except in the Golconda quadrangle where geologic mapping has been completed. Some of the long faults, moreover, appear to be more or less locally mineralized with long intervals of no evident mineralization. The following division is therefore made for present treatment:

1. Marion-Sheridan district; in Crittenden County; includes mines and prospects in and about Marion and for a distance of about eight miles west and eight miles north to include the so-called Columbia fault and the numerous faults immediately east; includes mines from the vicinity of Glendale southwesterly through Sheridan to and including the vicinity of Pleasant Grove.

2. Lola district; chiefly Livingston County.

3. Salem district; southwestern Crittenden and Livingston Counties.

4. Mexico-Claylick district; chiefly in Crittenden County.

5. Caldwell County mines; includes chiefly the mines east and southeast of Fredonia, to and including the vicinity of Princeton.

6. Outlying districts; including a few mines and prospects lying west and south of the area covered by the above divisions.

1. Marion-Sheridan District

In this district are included the majority of the most important mines of the past and present. Geographically it is within the borders of Crittenden County, covering about a third of that county west and northwest of the town of Marion. Also mines in the vicinity of Levias, slightly south of west from Marion, are included.

Within this district is what appear so far to be two of the most strongly mineralized zones of the entire Kentucky fluorspar field. In particular, two strongly mineralized fault systems of northeasterly trend cross the district at distances of approximately 4½ miles (the Columbia system of Ulrich's map) and 6 miles (the La Rue system of Ulrich) west of Marion. West and northwest of Marion the two systems and their numerous divergent and cross fissures have been extensively prospected and mined. At Marion, east of the railroad, another fault zone of northeasterly trend crosses the district and local mineral bodies on this (the Marion fault) have been successfully exploited in the immediate vicinity of the town. (See Lucile mine below.)

COLUMBIA SYSTEM

On the Columbia system of fractures are situated the Mary Belle (Kentucky Fluorspar Company), Franklin (Fairview Fluorspar and Lead Company, operating chiefly in Illinois) about 4½ miles west of Marion, Ada Florence (Kentucky Fluorspar Company) and Keystone mines; the abandoned Klondike, Memphis, and Columbia; several other small mines and prospects are also on this system. The vein system appears to embrace at least two very pronounced faults and several important divergent faults, and many small intersecting fissures. In the main fissures large and persistent mineral bodies have been exploited having the usual association of fluorspar, calcite, galena, and zinc blende. Locally on this system, as at the Columbia, and at Crittenden Springs, the veins were at one time exploited for zinc; elsewhere zinc values are generally low and negligible. In the vicinity of the Franklin and Ada Florence mines there appears to be a greater abundance of calcite. The presence of large bodies of calcite in fluorspar veins is by no means to be considered unfavorable to the presence of large concentrations of fluorspar, but possibly distinctly otherwise as the replacement relations of the two minerals suggests, and bodies of calcite may change laterally or vertically into important masses of fluorspar. The lead ore mineral, galena, is commonly present throughout this system, but nowhere appearing in mineable concentration, although it is recovered as a by-product.

Mary Belle Mine.

At this property of the Kentucky Fluorspar Company several shafts have been sunk on the main vein, three of which connect through the present workings. The main shaft (No. 3)

(14) Suface plant at main shaft of Mary Belle mine.

reaches a depth of 350 feet. The levels chiefly developed are at 200 and 250 feet. While the vein does not appear to attain great widths the ore bodies seem to be rather unusually persistent. The maximum width noted was ten feet; the 200-foot level was said to have furnished 700 feet of continuous vein matter varying from 4 to 10 feet in width. The vein pinches and swells at numerous places, but not so abruptly as is common in other mines. Both galena and zinc blende occur in the fluorspar "ores," the former being the predominant sulphide. A large body of galena has recently been reported at 300 feet.

The vein course between present shafts averages N 18° to 20° E; the dip is steeply west, nearly vertical in places. The walls are pronouncedly slickensided at the vein contacts and the vein matter itself, as the diagram shows (Fig. 15), has been strongly sheared; some of these shear planes are slightly mineralized with the metallic sulphides while others are without such mineralization.

Coarsely crystalline calcite is prominent in the vein though entirely subordinate to the fluorspar, and the two display the previously described replacement relations.

The footwall (east) consists of the thick Fredonia-St. Louis limestones, the latter probably appearing between the 200 and 300 foot levels. In places the Fredonia has been partly replaced

(15) Diagrammatic section of vein at a point in Mary Belle mine. (a) massive white spar with streaks of galena (black); (b) fluorspar "sand"; (c) much fractured fluorspar; (d) massive spar with disseminated galena.

by quartz near the vein, resulting in a "jasperoid" immediate wall-rock. Figs. 16 and 17 show a photomicrograph of this "jasperoid." It is to be noted that the rock also carries a small amount of disseminated grains of zinc blende replacing oolites and calcite of the wall-rock. In the hanging wall appears sandstone (especially in the upper part) partly quartzitized, and limestone. Very little shale is found; the stratigraphic horizon appears to correspond to about the middle of the "Birdsville." The hanging wall sandstone shows a high degree of shattering, in this respect contrasting with the footwall. It is not certain that the Mary Belle workings are on the main Columbia vein; it may be considered as being structurally connected with the Columbia system, and to partake of the mineralogical features of the Columbia vein except for the zinc values which are said to figure more largely in the latter.

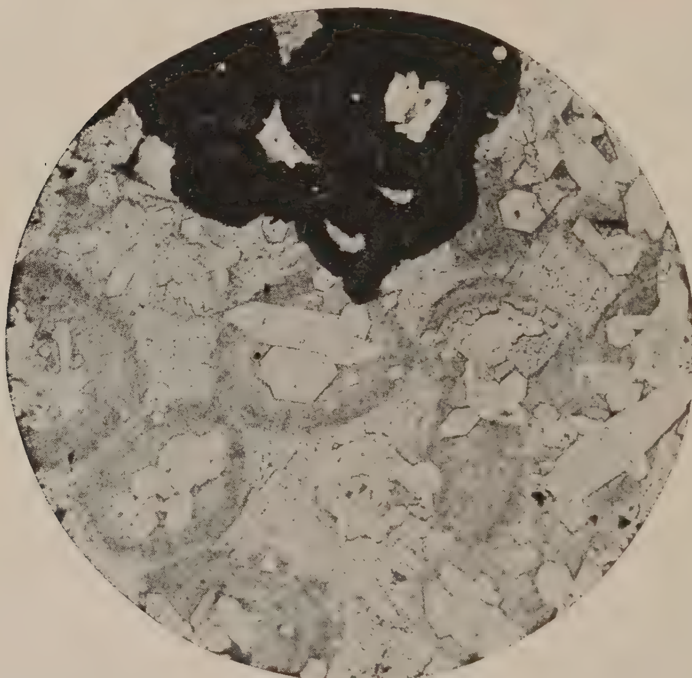
The Columbia Mines.

The Columbia mines have historical interest. The first shaft of the entire fluorspar region appears to have been sunk

(16) Photomicrograph (x12) of section of oolitic Ste. Genevieve limestone from footwall of Mary Belle mine showing replacement of rock by quartz crystals (clear, light patches bounded by sharp edges) and zinc blende (black).

on the Columbia property by Andrew Jackson in 1835. This exploitation was solely for the silver values carried by the abundant galena. At several times in the succeeding decades of that century development and exploitation were attempted and abandoned; during the Seventies a small smelting hearth was installed. No deep mining was done at any time, according to historical accounts. During the first two or three years of the present century deeper development (to 140 feet) was carried on, but since 1907 the mines have been abandoned.

The mineral association is the same as at other mines of the district, i. e., galena and zinc blende, fluorspar, calcite. Accounts of the property emphasize the concentration of lead and zinc minerals at this part of the Columbia fault zone, and give fluor-



(17) Photomicrograph showing details in texture of oolitic Ste. Genevieve limestone replaced by quartz crystals and zinc blende (black). Specimen from wall rock. Mary Belle mine. Enlargement of an area in figure 16.

spar a rather subordinate importance. Inasmuch as there is no access to underground workings, no definite statement regarding types of mineralization and vein structures can be stated. Judging from conditions generally found in the fluorspar field, however, it seems probable that the sulphides are of local concentration at the Columbia mine, and that fluorspar bodies may be found by continued development.

The course of the Columbia vein is here markedly different from the course at the Mary Belle mine, which is supposed by some to be on the Columbia vein. The trend as reported for the old workings is N 22° E for this vein. The footwall (east) is Ste. Genecieve limestone; the hanging wall consists of Chester series, shale and sandstone being reported in the accounts of earlier developments.

The silicification of sandstone, into quartzite, and of limestone here carries further the similarity between this deposit and other major veins of the district. The replacement of the limestone footwall by microscopic quartz crystals resulted in a jasperoid similar to that at the Mary Belle mine, and similarly with the latter, a considerable degree of impregnation of the limestone wall with zinc blende is reported.

According to recent advices, operations by the Kentucky Fluorspar Company have indicated the probability of a cross fault bearing northwesterly between the Mary Belle and Columbia mines. If later study shows this to be true, and the Colunbia vein to be a westerly displacement of the vein at the Mary Bell, the dissimilarity in vein courses may thus be accounted for. In this case the Columbia fissure will not, of course, continue south of the cross fault, nor will the Mary Belle lead continue north; also the cross fault itself will probably be found unmineralized.

Crittenden Springs Vicinity.

Continuing northeasterly for three to four miles from the Columbia mine a series of old and new workings shows a general continuation of the Columbia zone of fissures. Among the old mines are the famous Memphis and Klondike properties, which are situated on separate veins, but both of which probably diverge from the main Columbia fault. These two mines have been closed for several years. Materials in the waste piles show the usual association of fluorspar, coarse calcite, galena, and zinc blende, and Fredonia limestone, which apparently comprises one of the walls. At the Memphis mine numerous pits and shafts are distributed along a course about N 35° E; at the Klondike similar pits appear in trends from N 33° E to N 41° E. Both of these courses, if they may be taken as average trends of the two veins, indicate fissures that are probably divergent from the main Columbia fracture.

Klondike Mine.

Recently (July, 1922), Butler and Haynes, working under lease with the Aluminum Ore Company (owners of the Memphis and Klondike properties), have been reopening the Mitchell shaft of the Klondike mine to a depth of 90 feet with the operation of levels at 50 and 80 feet. Solid walls are met at 40 feet; both walls are Ste. Genevieve limestone. Some galena and a little zinc blende are associated with the vein fluorspar and coarse calcite.

Memphis Mine.

The present lessors of the Klondike mine are contemplating the reopening of the old Memphis incline shaft (July, 1922) under lease. It is expected that operations will be limited to about 100 feet. The Memphis incline at the time of abandonment had reached 250 feet.

Miscellaneous Mines and Prospects.

Other prospects and abandoned mines on the Klondike or Memphis, or closely related fissures, are the Union mine, about 300 feet northeast of the Klondike Mitchell shaft), and the Gill, Eclipse, Edwards, and Martin prospects between the Klondike mine and Crittenden Springs. The Union mine was being opened to shallow depth (75 feet) by the Kentucky Fluorspar Company in August, 1920.

At Crittenden Springs several other abandoned mines and prospects attest to earlier and unsuccessful attempts to develop. The waste pile of one of these (the Clement zinc shaft) contained only highly brecciated quartzite cemented by zinc blende and quartz.

Franklin Mine.

This mine is situated at a distance of approximately five miles nearly due west of Marion, and is one of the newer and more consistently developed properties of the field. Permanent plant and underground workings have been established by the Fairview Fluorspar and Lead Company, whose property in the

Illinois field has been one of the two largest producers of fluorspar in the country. The main shaft of the Franklin mine has been sunk to a depth of 380 feet (1920), and shaft No. 2, located 240′ northeast, to 150 feet. Levels are established at 100, 150, 250, 300 feet. The 250-foot level has been driven 700 feet along the vein.

The mine is believed to be on the same vein as the Mary Belle. The average vein course between the three shafts on this property is approximately N 29° E. The vein dips steeply, but variably, toward the west wall. The actual course of the vein

(18) Modern mine plant and company cottages at Franklin mine.

is very sinuous, and the average strike slightly less than the bearing stated above.

At one point the vein has been stoped to a width of sixteen feet, which is the reported greatest width of the fluorspar vein. In places it carries an abundance of the coarse calcite, which is partly replaced by fluorspar. In some parts of the vein, especially toward the surface, calcite is reported to predominate and to even constitute practically the entire vein matter. Lead ore (galena) is present in appreciable but very subordinate amounts, and is recovered as a by-product in the mill. At a depth of fifty feet the entire vein width of eight to nine feet is said to have consisted of coarse calcite. Sections of the veins at lower levels show brecciation of the footwall with prominent calcite interstitial filling, calcite included within the main fluorspar mass, and a chief vein filling of good quality fluorspar. Pieces of footwall limestone are scattered through a zone of a foot or more of mixed calcite and fluorspar, and the footwall also shows pronounced fracturing and subsequent "healing" by calcite.

The hanging wall consists chiefly of shale and sandstone, the latter quartzitized, and in its shaly aspect presents a contrast with conditions at the Mary Belle mine. No limestone was encountered in the hanging wall to a depth of 250 feet. The footwall appears below a depth of fifty feet and consists of Ste. Genevieve limestone. The stratigraphic relations thus revealed indicate a similarity with the Mary Belle as regards the footwall horizon, while the hanging wall differs from that of the Mary Belle in carrying much more shale. Both walls at the Franklin mine show pronounced slickensiding. Minor slip planes cut diagonally across the vein matter, indicating faulting subsequent to the period of mineral deposition.

The flow sheet of the Franklin mill is described in Chapter VIII.

Ada Florence Mine.

Adjoining the Franklin mine property on the southwest the Ada Florence mine of the Kentucky Fluorspar Company has recently been opened on the same vein. The new shaft of the Ada Florence is about 1200′ S 290° W from the main shaft of the Franklin. This shaft has been sunk to a depth of 150 feet (1920) and short drifts established at the 100 and 150 foot levels. Very little development has yet been done on this property. In former years two shafts, now abandoned, had been sunk; their positions and bearings are indicated in the sketch map.

In this mine the west (hanging) wall consists of quartzitized sandstone containing some thin intercalated beds of shale to a depth of 150′. The horizon appears to be lower Birdsville. The foot wall is Ste. Genevieve limestone.

The association of much calcite with some fluorspar corresponds to conditions reported in the nearby Franklin mine. On the 100 foot level the vein was seen to pinch, but a widening of the vein with further development southerly appears highly probable. The mine seems to be in a position favorable to satisfactory development.

On the 150 foot level a slight horizontal displacement of the vein was noted, the vein being cut off near the floor of the drift by the nearly horizontal slip plane. Conditions suggest that the lower portion has been moved easterly a few feet. A similar condition is reported in the old shaft 250 feet northeast, where the lateral displacement is said to equal about fifteen feet.

While calcite is of chief prominence at shallow depths, it is confidently believed that fluorspar values will increase with development to greater depths.

Keystone Mine.

About one-half mile southwest of the Ada Florence mine, in a direction S 28° W. and apparently on the same vein as the Mary Belle, Franklin, and Ada Florence mines, at least five shafts have been sunk to depths of 100 to 300 feet on the property of the Keystone mine. Started in 1904 by the Keystone Mineral and Mining Company, operations have been sporadically carried on by three companies. Data on early operations are given by Smith.[1] The mine was later operated by George D. Roberts and Company, with the development of two shafts reaching to 300 feet in depth, and finally in 1920 the property was being further developed by the Standard Spar Mining Company of North America, with the sinking of a new shaft in the hanging-wall 75 feet from the vein to a depth of 150 feet; at the time of the writer's visit the company planned to sink this shaft to a depth of 300 feet before cross-cutting and drifting. In sinking this shaft the formations passed through consisted of shale, in places very thinly bedded, to a depth of 135 feet, from which depth the shaft passed into quartzitized sandstone. The lower part of the shale formation became micaceous and sandy. The wall rock relations are obviously in harmony with those at the Franklin and Ada Florence mines, i. e., sandstone with some shale in the hanging (west) wall, limestone of the thick lower series in the footwall.

[1] Op. cit., Prof. Paper 36.

Coarse calcite, fluorspar and galena, comprise the vein minerals as seen in the waste from former operations.

Mines East of Levias.

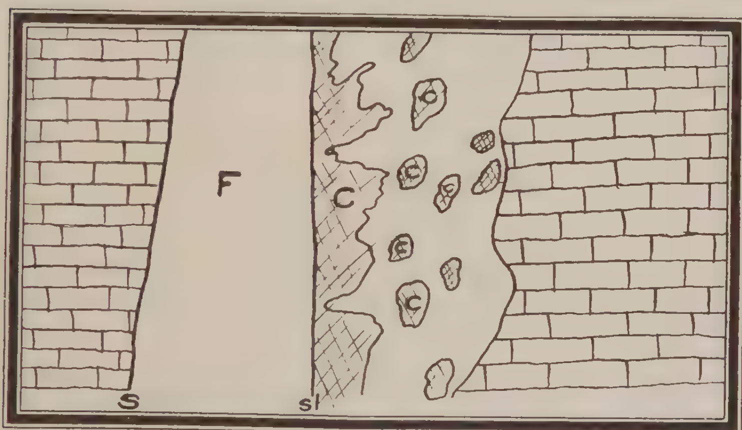
About one mile east of the village of Levias some small mines of unproven value known as the Eaton mines are situated on a fissure in limestone—probably the Ste. Genevieve—bearing approximately N 15° W and entering the Columbia fault (Ulrich) probably at a point just south of the Keystone mine. This group includes the Eaton mine and prospects and the old Standard mine. Numerous shafts and pits indicate the general course of the fissure. No considerable body of fluorspar appears to have yet been discovered. The mineral association is the usual one of calcite, fluorspar, galena, and zinc blende. Of particular interest is this group; first, because it appears to be on a fissure intersecting the prominent Columbia fault zone on which several properties of merit are located so that in the character and quality of the mineral association it probably closely resembles the vein of the Keystone-Ada Florence-Franklin mines, and secondly, because at one of the prospects a few hundred feet to the east of the Eaton-Standard vein the presence of igneous material is indicated. No information regarding the underground conditions at this prospect is available, except as gleaned from an examination of the waste pile. This contained an abundance of peridotite, some metamorphosed limestone from the dike contact, and vein matter consisting of calcite, fluorspar, galena, and zinc blende. (See remarks under dike, east of Levias, Chapter III.)

LA RUE AND ASSOCIATED FAULTS.

The La Rue fault zone comprises a system extending from the east side of Hardins Knob to the vicinity of Glendale, passing east of the village of Sheridan, and having a northeasterly trend. The average bearing of the main zone is about N 40° E. Diverging and intersecting veins, genetically associated with the main vein, appear to be numerous. Several mines of importance have been exploited on this system, and a considerable amount of prospecting has been carried on during many years. Chief among the operations at the time of this investigation were the developments at the Holly, Big Four, Perrigen Springs, Deer Creek, and K-K properties, while prospecting and shallow gravel mining were being carried on at the Hay Shed, Sullinger, and the Clark and Haynes (near the old Commodore, abandoned mine) prospects. This system comprises one of the most important mineralized zones of the Western Kentucky field, judging from past developments and present indications.

Holly Mines.

At the Holly property south of Sheridan two shafts were in process of development, one on each of two parallel veins

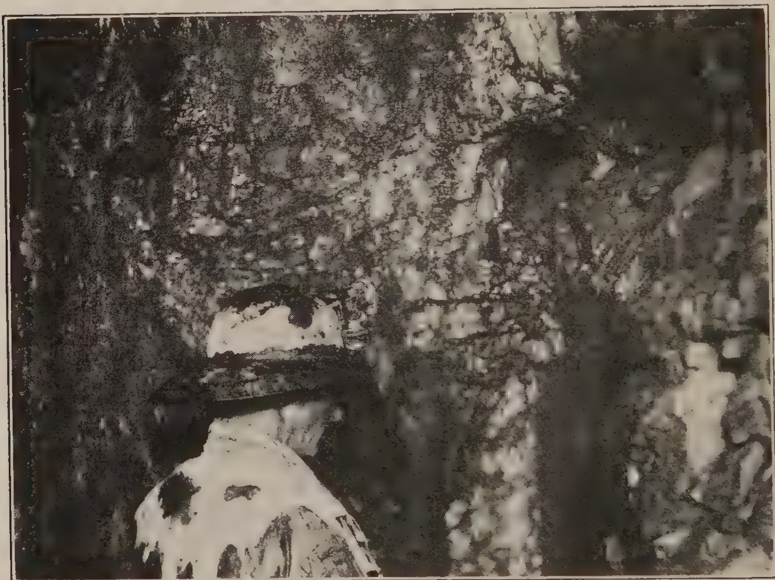


(19) Section of vein on 75 foot level of Holly mine. F, fluorspar; C, calcite; s, thin selvage on limestone wall; sl, slip surface.

known as the Holly and the Jones veins. These appear to intersect, and to be structurally closely related to, the La Rue fault. Contrasting with the northeasterly course of the latter, the Holly and Jones leads have an approximate bearing of N 28° W. The two veins are about 500 feet apart. The Holly vein dips steeply northeasterly at approximately 80°. Past operations have been partly in the surficial mining of gravel fluorspar and partly in the development of shafts to shallow depths. Recent work has been confined to the development of a level at a depth of 75 feet in shaft No. 1 on the Holly vein, and to the sinking of a prospect shaft on the Jones lead with the idea of permanent development.

Fig. 19 shows a section of the 75-foot level face at one time during its development.

Both walls of the Holly are of the lower thick limestone series, the hanging wall of Fredonia, and the footwall of lower Fredonia or upper St. Louis. The hanging wall is much slickensided with the development of a thin gouge. At both walls the vein contacts are sharp.



(20) Face of fluorspar vein in 75 ft. level, Holly mine No. 1 shaft.

The vein matter consists of fluorspar and calcite in their usual paragenetic relations, and disseminated galena. No zinc blende was seen at this shaft, but the mineral appears to have been a prominent vein constituent in the workings to the northwest on the same vein.

In Fig. 19 the vein is seen to be somewhat banded, due in part to subsequent displacement within the vein matter, one portion containing rounded fragments and rhombs of calcite suspended in the fluorspar mass, another portion containing coarsely crystalline fluorspar of high purity and carrying a small amount of disseminated galena. The vein appears to possess the characteristic types of variability of the main northeasterly veins.

Perrigen Springs Mine. (Crystal Fluorspar Company.)

East of the Holly mine about one-quarter of a mile a new prospect was opened in the summer of 1921 on a small vein having a bearing nearly parallel with that of the Holly vein. The vein matter consisted of crystalline fluorspar between two rather indefinite clay walls; the maximum total vein width seen was two feet, observed in the single cross-cut which comprised the extent of the underground development at the time of the writer's visit. The particular interest associated with this small prospect was the association of the vein with a much decomposed peridotite dike about ten inches in width and separated from the vein by a few inches of clay. Later advices state that further developments exposed the dike in contact with the vein matter. At one point the dike has a bearing of N 15 W, which suggests an intersection of the two. Developments were not extensive enough to disclose any other structural or genetic relations between the dike and vein.

Later in 1921 this shaft was abandoned and two shafts sunk about 1,000 feet along the course of the vein, northwest. Several hundred feet of drifting have been done on two levels. The newest shaft is 96 feet deep, with a level at 90 feet.

A dike two feet in width is reported to form the northeast wall (hanging) to the vein which is said to have a maximum width of 3½ feet. Limestone forms the vein footwall, and also the hanging wall of the dike. The average bearing of the vein is aproximately N 17° W. Both zinc and lead sulphides are in evidence in the vein matter. Calcite is prominent.

Big Four Mine.

This mine is about one-half mile east of the Holly mine and is situated on the La Rue fault system. No workings were accessible. Past operations have comprised open-pit mining and some underground development. Calcite, galena, and a prominent amount of zinc blende accompany the fluorspar. Considerable development is planned by the present owner, Mr. A. H. Reed, who has recently sunk a shaft to a depth of 100 feet.

Mr. Reed states this mine to be in part on the Big Four fissure of the La Rue system, i. e., a prominent fault plane in the footwall block of the La Rue fault and which, because of lower dip, probably intersects the La Rue at depth. Drilling into the hanging wall of the La Rue fault at the Big Four mine disclosed a quartzite formation, while the footwall (west) consists of the thick limestone series, apparently lower Ste. Genevieve, or possibly upper St. Louis. The Big Four and main La Rue fissures are less than fifty feet apart at the Big Four mine. Operations are chiefly on the La Rue vein.

Recently (summer, 1922) vein widths up to 18 feet were reported, drifting having been done in both directions on the 100-foot level.

Zinc ore (blende) is said to be prominent in parts of the vein breccia, but not of general distribution, being present in more or less concentrated masses. Lead ore (galena) appears more generally in the vein material, and is recoverable as a by-product.

A modern mining plant has been erected, and large scale operations are planned. The Big Four mine is advantageously situated on one of the most impressively mineralized fault systems of the entire fluorspar district.

La Rue Mine.

On the La Rue vein a few hundred yards northeast of the Big Four mine are the abandoned workings of the La Rue mine. The waste piles show a considerable amount of zinc blende associated with fluorspar and coarse calcite; galena is present in the material, but in small amount. The wall rocks are similar to those of the Big Four mine, i. e., the west (foot) wall is limestone of the Ste. Genevieve-St. Louis series, and the footwall is quartzite and some shale of the "Birdsville" series. The dip of the vein is reported to be about 70° toward the southeast. The old inclined shaft is stated to be 250 feet deep. A heavy concentration of zinc ore (blende) is said to have been encountered near the shaft which gave place southerly to fluorspar; the reported lateral extent of the zinc ore body is 150 feet, approximately, on the lower level. Thus together with the nearby Big Four mine a notable amount of zinc characterizes this portion of the LaRue vein system. Several divergent minor veins along the LaRue system also carry appreciable zinc, such as at the Hayshed and Deer Creek prospects.

Hayshed Prospect.

This is situated on a minor fissure into the footwall of the LaRue vein, where massive fluorspar, coarse calcite, and much lead and zinc appeared in the vein matter removed in the shallow prospect shaft.

Deer Creek Prospects and Vicinity.

Northeast of the LaRue mine. In this neighborhood several prospects have been opened both on the main LaRue fault system and on an associated fault to the east. This latter—called the "Glendale"[2]—fault at a surface exposure has a westerly dip of 50° to 55°. Dipping toward the LaRue fissure it must intersect the latter at a shallow depth, inasmuch as these two faults are, in one place at least, not more than 150 feet apart. Several cross fissures along this portion of the LaRue system are somewhat mineralized. The fracturing in this section of the LaRue system appears to be complicated, but two well defined northeasterly breaks are in evidence, comprising the chief fracture of the LaRue fault and a pronounced nearly parallel fracture of opposite dip to the east in the Chester sandstones and shales. All the original fractures of the LaRue system will be found to be mineralized, but chief interest is to be directed to the pronounced fracture having the St. Louis limestone in the west wall.

Hayward Prospect.

This prospect, apparently on the LaRue system, is on the north side of the Marion-Sheridan road east of the fork with the road leading to Glendale, and about one mile east of Sheridan. The St. Louis-Ste. Genevieve thick limestone series appears to form the west (hanging) wall, with the Chester series forming the east. There has been very little development on this prospect, and no underground workings were accessible. Mr. A. H. Reed reports an easterly dip of 70° for either vein at this point, a zinc carbonate product at a depth of 50 feet, besides a pro-

[2] Not, however, the "Glendale" of Ulrich, Prof. Paper 36.

nounced vein of fluorspar, and a quartzite block caught between the main walls, a structural feature which is said to be common on the LaRue system. Purple fluorspar, galena, and zinc blende are in evidence.

Further prospecting is being done in this vicinity by the Warren Mining Company, who have sunk a shallow shaft in clay on the southwest side of the road. This shaft, other prospects to the southwest, and the Hayward prospect, to the northeast, mark a general vein trend of N 53° E; this direction may not be exactly the true vein course, due to the slow creep of the surficial clay, which in this vicinity is more than 50 feet thick.

Mitchell Prospect. (Warren Mining Company.)

About 400 feet N 37° E from Hayward prospect, a recent shallow shaft on or close to the LaRue fault. Abandoned. Footwall, limestone; hanging wall, shale and sandstone. The footwall material shows calcite seams; some lead mineral accompanies fluorspar.

K-K Mine.

Operations were being carried on in 1920 by the U. S. Fluorspar Company; footwall shaft about 120 feet deep, with a level nearly 300 feet long; at the north fan a pinch was encountered. Much of the exploitation was in clay residuum, solid walls being encountered near the bottom. The footwall is Ste. Genevieve limestone. The mine is on or close to the LaRue fissure, possibly on a parallel subsidiary fracture in the footwall of the LaRue.

Commodore Mine.

Situated on the LaRue fracture, near Glendale School, about two miles northeast of Sheridan. At this mine (abandoned and inaccessible at time of investigation) are found limestone, probably Ste. Genevieve, in the footwall (west), and quartzite and shale in the hanging wall; much shale is said to have been encountered in the latter. At 265 feet depth, White shaft, the footwall is reported as limestone.

The main shaft is stated to be 300 feet deep. The mine was operated between 1910 and 1914 with the development of levels at one shaft at 37 feet, 66 feet, 100 feet, 185 feet, 215 feet, and 265 feet.

The greatest total vein width is reported to have been 26 feet, on the 185-foot level; zinc ore comprised 19 feet of this. Pinches were met at several places on several levels.

Zinc values appear to have characterized this mine; calcite; galena, and a little fluorspar from the vein matter are in evidence in the waste piles. In 1918, fluorspar was mined from the upper portions of the vein.

Other Prospects Along the LaRue System.

Numerous prospects, among them the Sullinger and Glendale pits and shallow shafts, mark the course of the LaRue fault between the K-K and Commodore mines. Along the vein course northeast of the Commodore, Clark and Haynes have recently prospected and mined in open cuts. Except at the Glendale shaft, the workings appear to be practically confined to the gravel fluorspar zone, so that conditions between solid walls are little known along these locations.

MARION FAULT.

Lucile Mine.

This mine is situated a short distance south of the Illinois Central Railroad station at Marion.

The mine is of particular interest in its comparative remoteness from other mines and prospects, the nearest producing mines being nearly five miles west, while to the north and east no fluorspar veins have apparently been yet discovered. The Lucile property has been extensively exploited by the Gugenheim Mining Company. The mine is now completely abandoned (1922).

The wall rocks at the Lucile mine are largely shales and sandstones of the Chester series, only thin bedded limestones being occasionally met with, except at a depth of nearly 250 feet where a massive limestone is present in the footwall (east).

Because of the large amount of shaly beds in both walls at this mine the vein course, width, and dip are greatly variable. The main fault fissure appears to be much less well defined than in mines where at least one wall consists of the lower thick limestones. Courses of the vein are to be noted from N 24° E to N 70° E.

Several levels have been worked through two shafts, to a depth of 265 feet. The vein matter is not continuous, but winds sinuously through the much fractured walls. Pockets and lenses of ore appear to be the rule, rather than a vein which is continuous for any considerable distance. Vein widths six to eight feet have been worked. The vein shows throughout the mine much fracturing and many minor displacements. Persistent shears having a northeasterly dip cross the vein at numerous points, and associated close fracturing or sheeting is pronounced.

Operations were suspended early in 1922, due to the exhaustion of ore bodies. In the hope of finding an extension of vein at the north, the owners had previously opened a shaft several hundred feet northeast of the main shaft, along the suggested strike direction of the vein. Finding fluorspar, a drift was run southwesterly, which failed to connect, however, with the old workings at the 90 foot level, as was expected. A cross-cut of 35 feet from the level in the old workings was driven easterly into the newly developed ground, thus leading to the conclusion that two veins were existent. The supposed new vein was found to pinch out at the south face.

Shears, similar in situation to those common in the old workings, are also pronounced in this newer drift. It is believed probable that the original vein had been offset along the general direction of these slickensided secondary "slip" planes, and that one of the two vein masses is only the decapitated portion of the main vein. While it is believed that wall rocks such as exist at the Lucile were generally unfavorable for the deposition of large veins, it is still possible that exploration to depths of the Ste. Genevieve-St. Louis limestones may disclose an important and more continuous vein mass.

Lola District.

The Lola district is chiefly confined to the Deer Creek valley in the northeastern part of Livingston County, and the adjoining territory of western Crittenden County. Most of the mines and prospects are within a radial distance of three miles from the village of Lola.

Extending southwesterly from Lola a somewhat localized but complicated area of faulting has been mapped by Dr. Weller.[3] Separated from this belt by an unfaulted belt of one to two miles in width, another area of faulting of even more pronounced degree merges at the southeast and east into the Salem and Sheridan districts. Northeast of Lola faulting is absent over a very considerable area, while at the west but two faults dissect a general unfaulted belt of several miles breadth. These two faults trend northerly into a rather unimpressive fault-area extending north to the Ohio River. Thus in the Lola district it would appear that satisfactory prospecting could be done only toward the southwest, and (more remotely from Lola) toward the southeast and east in the faulted belt between this district and the Salem and Sheridan districts.

Up to the present time there has been little successful prospecting in the Lola district. In view of the existence of important fluorspar bodies which have been developed to shallow depths (to 165 feet) at the Bonanza mine about two miles southwest of Lola, it would be justifiable for further prospecting to be carried on in the faulted belt south and southwest of this mine. Although the Lola district appears to be somewhat isolated and on the flank areas of pronounced mineralization, the existence of vein matter in the Bonanza mine reaching a total width, fluorspar and coarse calcite, of over 9 feet at one point in the drifting, is significant of a possible local mineralization in which ore-bodies of economic importance may be found. Prospecting should be carried on conservatively.

Bonanza Mine.

This mine, owned and operated by the United Mining Company, is situated on the east side of Foreman Creek, one and one-half miles southwest of Lola. A "quartzite reef" capped by lower Chester sandstone marks the general trend of the Bonanza fault, and forms its hanging wall block on the southeast, while

[3] Weller, Stuart; Geology of the Golconda Quadrangle; Kentucky Geological Survey, 1921.

Fredonia limestone constitutes the footwall. At the elevation of the shaft, located nearly at the base of the sandstone ridge, Fredonia limestone appears also in the hanging wall, so that in the mine workings both walls are of this formation, the displacement being less than the thickness of the Fredonia limestone (which is 180 to 200 feet), and, according to Weller,[4] "may not be over one hundred feet." Weller gives the average strike of this fault as N 33° E. In the mine workings, the vein is found to be somewhat sinuous.

The vein attitude is nearly vertical, prominent slickensided walls giving a dip angle of 83°.

The Bonanza mine, though somewhat isolated from other worthy prospects and mines, has produced a large quantity of high grade fluorspar, partly of acid quality. It has already been pointed out that prospecting in this district to the southwest might be productive.

The mineral association consists of the typical coarsely crystalline calcite and practically colorless fluorspar. Sulphides are conspicuously absent from the ore bodies, although very small quantities have been reported in nearby prospect shafts. The replacement of calcite by fluorspar was excellently displayed at the working faces. Narrow replacement veinlets of purple spar appear in the limestone walls. Pinches are met with on all levels. On the 60 foot level vein widths of three and four feet were noted; at the north face of the 165 foot level a vein width of 9¼ feet was seen, consisting of massive colorless fluorspar, including numerous rounded patches of calcite, the fluorspar content predominating.

At places subsequent shearing along the vein matter has dragged in fragments of limestone.

Due to the absence of sandstone walls and of sulphides (particularly zinc blende) the fluorspar from this mine should be characterized by a very low silica content.

At a prospect shaft about two hundred feet northeast of the main shaft, six feet of vein matter, partly calcite, was seen.

The Bonanza mine is the only productive mine of the Lola district at this writing.

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[4] Op. cit., p. 130.

Mann Mine.

In the immediate vicinity of the Mann mine, 1½ miles northeast of Lola, prospecting has been done at several pits and shafts, with no success in the location of fluorspar bodies. At the Mann mine, abandoned, only coarse calcite in Fredonia limestone was found in evidence, no associated fluorspar being seen in the calcite of the waste piles.

The mine is said to have been worked for zinc carbonate, at shallow depths, which changed to zinc blende. Evidences of appreciable mineralization in this neighborhood are wanting.

Other prospects have been productive of zinc carbonate in small amounts, such as the McDowell mine, a short distance northeast of the Mann mine.

Particular encouragement cannot be offered fluorspar prospectors in this vicinity.

Prospects at Lola.

Between the Mann mine and Lola, several shafts have been sunk on a northeasterly trending vein, probably the continuation of the Bonanza fault, or a closely allied fissure. All workings are abandoned. Much barite and a very small amount of fluorspar are in evidence in surface piles; the workings probably were of very shallow depth, situated in the residual clay mantle. The locations along the general creek flat make it probable that solid walls will not be encountered within fifty to seventy-five feet. In this neighborhood the northeasterly trending Bonanza fault probably dies out.

Corn Mines. (Pleasant Grove.)

Abandoned. Developments here consist of several shallow shafts and a large open cut apparently at the intersection of several minor faults. The location of this and several other abandoned workings (including the Bebout, Belt, and Keyes prospects) appears to be a slightly mineralized area about midway between the Sheridan and Lola districts. No mines are now operating here.

North of Lola.

In the faulted area north and northwest of Lola, fluorspar has been discovered at several prospects for several miles back from the river bluff, but no important degree of mineralization has been yet disclosed.

Salem District

This district, of which the village of Salem is the center, lies chiefly in eastern Livingston County, extending only slightly into Crittenden County to include a few mines and prospects along the Evening Star and Stevens faults of Ulrich's nomenclature. Fluorspar mined in this district is hauled by wagons to the railroad siding at Marion. Much prospecting has been done in the territory, with the development of a few mines that have justified development. Mineralization in this district appears to be chiefly along a zone of faulting which includes the Evening Star and Stevens faults. In the areas of prospecting and mining the Ste. Genevieve-St. Louis limestone series comprise one or both walls in all cases so far observed. About two miles north of Salem considerable prospecting and some shallow mining have been carried on along several faults of northeasterly bearing, but which may be of local extent only.

Liberty Bond Mine. (New Watson Mine.)

This mine is operated by the Eagle Fluorspar Company, Salem, Ky. It is situated in the general valley flat one-half mile south of New Salem church and about three miles east of Salem. In this area of Ste. Genevieve limestone a thick residual clay mantle obscures structural conditions of the immediate vicinity of this mine. Numerous prospect shafts and pits, together with the present working shaft, at which fluorspar showings were obtained carry a general course of N 65° E. It is probable that this rather closely indicates the course of the vein. The shaft is 95 feet deep, 75 feet passing through residual clay. Solid walls are said to appear at the bottom. Both walls are of limestone.

The fluorspar carries a small amount of lead mineral and calcite. A high grade milled product is obtained.

Two Brothers Mine (Formerly Watson Mine).

Pope Brothers of Louisville, Ky., are operating this mine, at which work had ceased in 1919, after two years of operations. The mine was originally prospected in 1904.

The shaft is 250 feet deep; present working is being restricted to 150 feet, at which depth the walls are not solid. Much drifting has been done in former times.

(21) Surface plant at Liberty Bond mine, Salem district.

Materials in the waste piles of former operations indicate the common mineralogic associations here of fluorspar, coarse calcite, and sulphides.

In this vicinity several minor fractures are associated with a main break of northeasterly course; the exact course is not established, but follows the general direction of the low ridge, possibly through the abandoned Fuller mine, the Yates prospect (C. W. Haynes and others), and the Conyer and Settles prospect, one-third to one-half mile northeast. It is probable that this break and the vein of the Liberty Bond mine are associated fractures.

Fuller Mine and Vicinity.

Abandoned. Located about one-half mile northeast of the Two Brothers mine, on the north side of the Salem-View road. Calcite, fluorspar, zinc blende, and galena are in evidence in the waste piles. The hanging wall (southeast) is a Birdsville sandstone; the footwall consists of Ste. Genevieve limestone. No considerable amount of mining was done here.

Conyer and Settles Prospect.

About two hundred feet S 65° W from the Fuller mine. The prospect shaft is 50 feet deep in Ste. Genevieve limestone (footwall). The hanging wall is quartzite. Fluorspar associated with coarse calcite and with a slight amount of sulphides make up the vein matter. This is probably on the same vein as the Fuller mine.

Yates Prospect.

At this prospect (opened summer, 1922) very little has yet been done. It appears, however, to be on the same vein as the Watson mine (Two Brothers mine) or a closely associated fracture. It has a bearing of approximately S 65° W from the previously described prospect, the distance between them being about one-eighth of a mile. Solid walls are not yet met at 50 feet. The true vein is probably slightly up-slope from the present prospect shaft.

Hudson Mine.

The American Fluorspar Company; operations at the Hudson mine, 2½ miles southwest of Salem, consist of two established shafts, and a large open cut 200x150 feet and up to about 75 feet in depth.

At the shaft, not in operation at the time visited, Fredonia limestone appears to compose one and possibly both of the vein walls. Developments are insufficient here, however, to predict the nature or extent of mineralization in this locality. The course between shafts, probably indicative of the vein strike, is N 67° E.

While fluorspar is in evidence at this property, interest has been directly chiefly toward the mining by open-cut methods of a body of zinc carbonate. A considerable quantity of this type of ore has been obtained. Through the pit, whose rough dimensions have been given above, two narrow peridotite dikes carry a nearly north-south trend. The course as determined at one outcrop is N 7° W.

The Two Bachelors Mine. (Known also as the Babb mine.)

Owned by the Pope Mining Company, Louisville, Ky. This mine is situated two miles north of Salem, east of the Salem-Irma road. The mine has been recently operated, but was not open at the time visited.

(22) Open cut, mined for zinc carbonate, at Hudson mine, 3 miles south (by west) of Salem. Pit crossed by two narrow dikes, not apparent in picture.

The footwall here consists of Fredonia limestone, the hanging wall chiefly of sandstone, quartzitized.

Coarse calcite accompanies the fluorspar, as also do zinc blende and galena, the latter in very small amounts.

The chief level is stated to be developed at 190 feet depth.

The course between shafts on this property is N 55° E. A nearby shaft, owned by the Eagle Fluorspar Company, and not now operated, is apparently on the same vein, about 400 feet northeast of the Babb shaft.

Guill Shaft.

This is an abandoned shaft about 1 mile northwest of the Two Bachelors mine. No information available. Apparently not extensively prospected.

Red Fox and Crosson Cave.

About three-quarters of a mile southeast of the Two Bachelors mine a line of prospect pits and shafts extends northeasterly (N 35° E) from Crosson Cave, including the Red Fox mine and Crow prospect.

At Crosson Cave some prospecting has been done, but has not met with much success. Here very narrow veins of fluorspar appear in joint seams of limestone and run in several directions.

The Red Fox mine (operated by E. G. Stribling) had, at the time visited, a prospect shaft sunk to a depth of 50 feet. Fredonia limestone forms the east wall, sandstone and shale the west (hanging) wall.

Nancy Hanks Mine and Vicinity.

The Nancy Hanks, Cullen (Evening Star), and Morning Star mines are situated on a fault of northeasterly bearing, crossing the Salem-View road about two miles southeast of Salem. The mines and associated prospects are located on both sides of the road, through a distance of one-half mile.

At the Nancy Hanks mine (west of road) an inclined shaft 310 feet deep had been worked in 1908; operations since that time have been confined to shallow depth mining at several periods of activity. Numerous pits and shallow shafts are in evidence. Both walls are said to be limestone at 55 feet. The vein dips southeasterly. Coarse calcite and sulphides occur with the fluorspar. Vein widths of 4 to 8 feet were reported. Mining in 1921 was being done by Myers and Crider.

On the east side of the Salem-View road a line of prospects leads to the Cullen (Evening Star) mine, abandoned. Considerable zinc is said to have been found here associated with the fluorspar. Attempts were made to devise a mill for the separation and recovery of both zinc blende and fluorspar, through the use of fine screening and sizing, and pneumatic concentrators. The mill was unsuccessful.

4. Mexico-Claylick District

The area designated as the Mexico-Claylick District embraces three general fault zones extending between Mexico, Claylick Creek, and View. It is practically confined to southern Crittenden County in the area between Claylick and Livingston Creeks. The points of shipping are at Mexico, 7½ miles south of Marion, and Crayne, 4½ miles south of Marion, on the Illinois Central Railroad.

In this district the pronounced degree of faulting has brought the Ste. Genevieve-St. Louis series to the horizon of the present surface along all these major zones, and it is to these belts that the important mines and prospects are confined.

This district is one of the two principal producing districts of the entire field, and gives evidence of a degree of mineralization exceeded only by the Marion-Sheridan and the southern Illinois districts. Of chief development is the fault system extending from Mexico to Frances, known as the "Tabb" faults. This system has been described as a series of fault blocks "en echelon" (Ulrich & Smith, op. cit.). The fault fissures along this system are numerous and pronounced, intersecting in many points, rather than running in general parallelism.

The mineralogical character of the veins is similar in all respects to that of the veins of other districts. The vein courses become more easterly than elsewhere, however, the easterly bearing increasing from the westernmost system to the easternmost. In the latter, in the vicinity of Mexico, the general strike bearing of the Tabb fault system becomes 80° to 85° E. Locally along the system, veins with courses nearly east-west are found; at the Keystone one vein course is N 79° W.

The mines of greatest development are on the Tabb system, Mexico.

Pygmy Mine.

Abandoned. Owned by the Rosiclare Lead and Fluorspar Company, of Rosiclare, Illinois; two shafts (250 and 300 feet deep) along a course of N 87° E, about ¾ of a mile south of Mexico railroad station, on both sides of Illinois Central R. R. The waste piles show the characteristic vein features, i. e., the common mineral association, and the calcite-seamed oolitic Ste. Genevieve limestone wall-rock. The vein is reported to carry much calcite, with fluorspar pinching out to inconsiderable proportions. The mine occupies the eastern end of the Tabb system, which probably dies out easterly into an unfaulted area.

Haffaw Mine.

The Haffaw mine of the Aluminum Ore Company is situated one-half mile west of the Pygmy mine. The course between the Haffaw main shaft and the Pygmy shaft is N 70° to 75° E, marking the general trend of the Tabb fault zone in this vicinity.

(23) Plant and cottages at Hafffaw mine, Aluminum Ore Co., Mexico.

The Haffaw is one of the best developed mines of the entire field. The main shaft, sunk in the footwall, was 307 feet deep when visited, with levels established at 70, 100, 150, and 200 feet, while a level of 300 feet was in anticipation.

The vein dips steeply to the north. On the 200 foot level south, a vein dip of 75° was noted, this being more pronounced in hade than elsewhere.

Calcite is prominent in parts of the vein, frequently "spotted" through the main vein filling of fluorspar. The vein carries both lead and zinc values.

Slight displacements of the vein are prominent, especially along nearby shears, cutting very sharp angles through the vein matter. This type of subsequent displacement caused an apparent widening of the vein at point where an 18 foot body of fluorspar was removed.

The flow sheet of the modern concentrating plant is given in the chapter on milling.

Keystone Fluorspar Company. (Blue and Marble Mine.)

Main shaft one-half mile west by south of Haffaw mine, on the Tabb fault system. Owners, Keystone Fluorspar Company; operated under lease by Meacham and Sloan, Hopkinsville.

(24) Section of vein at a point on 145 ft. level, No. 3 shaft, Blue and Marble mine, Mexico district. a. band of fragmental spar, calcite, galena and rock; b. massive spar spotted and streaked with galena; c. spar with inclusions of calcite; d. zone of galena; e. spar with inclusions of calcite; f. rock; g. massive fluorspar.

Several shafts have been sunk on this property during the course of many years of prospecting and mining. About 100 feet of drifting have been driven along a winding vein course between limestone walls. The greatest depth is 200 feet, and working levels are established at 150 and 200 feet; other levels twelve in all, have been abandoned. As in the Haffaw mine, vein dips are steeply north, usually around 80°. The footwall is considerably slickensided in places; a calcite-fluorspar breccia is particularly prominent near and at the hanging wall, while inclusions of corroded calcite are abundant through much of the vein material. Fluorspar bodies up to 8 feet in width are separated by gradual pinchings of vein matter.

Horizontal displacements of the vein are noted; at the east face of the 150 foot level, as example, the upper portion of the vein has been offset to the northwest entirely beyond the drift walls. A gougy seam two to four inches thick occupies the nearby horizontal slip plane, below which the vein material shows dragging in the direction of offset.

Lead ore (galena) is recovered in milling as a by-product.

In shaft No. 1 (200 feet) quartzite is reported in the hanging wall to a depth of 75 feet. At depths of 100 feet in all shafts limestone generally appears in both walls.

Tabb Mine.

Formerly West Kentucky Ore Company, now absorbed by Kentucky Fluorspar Company. One of the earliest mines of the field, being first opened in the late eighties, though production has been most continuous since 1900.

Numerous shafts and pits are in evidence. Wall rock conditions and vein attitudes are similar to the Blue and Marble mine described above. Limestone comprises the entire footwall (south), sandstone and shale appear in the hanging wall above 75 feet. At the surface the Chester sandstones, much brecciated and seamed with fluorspar, outcrop in proximity to the vein.

The greatest vein width reported is 17 feet; the average is probably close to 5 feet. Zinc and lead sulphides appear in the vein material in minor amounts, and zinc carbonate has been mined at the surface from shallow pits along the vein. Barite occurs in the residual clay over the limestone footwall, but does not appear in the solid vein.

Wheatcroft.

Not in operation when visited. Surface plant and new shaft in process of construction, by present owners, Kentucky Fluorspar Company.

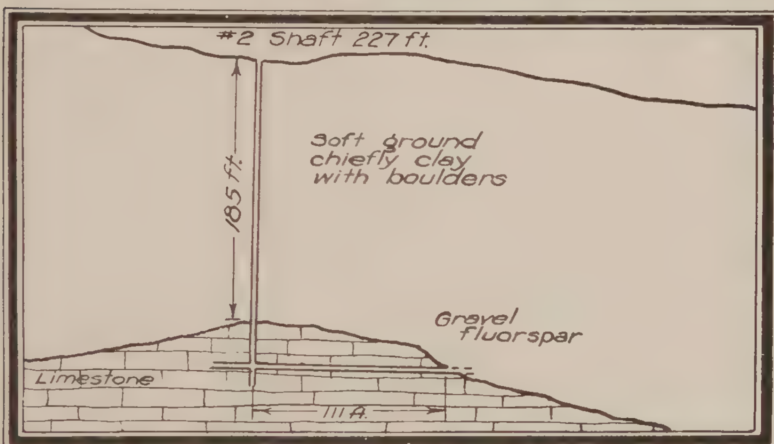
Situated on Tabb system, west of Tabb mines.

Tabor Mine.

On Tabb fault system, west of Wheatcroft. Not in operation when visited. Numerous shafts and prospect pits along the course between Wheatcroft and the Asbridge mine.

Asbridge Mine.

Operated by Roberts Fluorspar Company, Marion. Situated on the Tabb system, west of the Tabor mine, and about 2½ miles from Mexico. The main shaft is 250 feet deep. Residual clay walls to nearly 200 feet, below which limestone walls appear. The average vein width is said to be six feet. Calcite is prominent at the levels below 200 feet when solid walls prevail. Three shafts to depths of 300, 170, and 187 feet have been sunk. At numerous places the vein widens out as dispersed gravel spar in the clay matrix, with some portions mineable through a width of 25 feet.



(25) Diagram illustrating possible conditions in a fluorspar deposit of deep secular decay. Conditions as described at Pogue mine.

Pogue Mine.

Owned and operated by the Kentucky Fluorspar Company. Located about 275 feet south of west of the Asbridge mine, and is therefore about 2½ miles west of the railroad ore storage yards at Mexico. On the Tabb system.

The shaft is stated to be 227 feet deep, driven in vein material; the spar is pockety, however, and forms an irregular much widened "gravel" deposit in residual clay (streaked with sand) for the most part, limestone boulders coming in at depth; rock walls, both of which are limestone, come in at 185 feet; above this depth, boulders of limestone appear in the footwall side (south) and some of sandstone in the hanging wall.

Due to the comparatively great depth to which residual decomposition and disintegration of the walls have proceeded, pockets and "blankets" of gravel spar are typical above the solid walls, necessitating a caving method of mining. This has resulted in a general caving of overburden from the surface down. The widest reported "pocket" in the clay residuum was 35 feet. The level at 225 feet, in rock at the shaft vicinity, is said to pass into "gravel" deposit at a distance of 111 feet, passing from practically solid walls into clay and boulders, indicative of the vertical irregularity of the contact surface between solid rock and its clay overburden. See Fig. 25.

Much calcite is reported in the solid vein matter at depth.

Matthews Mine.

Davis Mining Company (1920), ¾ of a mile southwest of Frances. Two shafts on Matthews property being opened to shallow depths (60 and 90 feet). No solid walls are found at these depths, the deposit consisting of superficial fluorspar gravel in clay derived from limestone.

Adjoining properties are the Pogue (east) and Yandell (west).

The earlier workings of the Matthews mine were continuous with workings on the T. J. Yandell land, the same vein being worked on this land at what was at one time called the Kentucky mine.

Yandell Mine.

Kentucky Fluorspar Company. The territory now included by the Yandell mine extends for over one-third of a mile along the Tabb system, and constitutes the westernmost development along this line of mineralization. At the time visited, the present working shaft had a depth of 85 feet; drifting with a very sinuous course appears to follow two vein positions. Solid walls are not met at this depth, so that the mine becomes another of the numerous "soft-ground" or "gravel" mines. Limestone boulders appear in the clay walls. The fluorspar body has been spread laterally in places by the slow creep of the clay matrix, making "gravel" fluorspar bodies up to 36 feet in width. The deposit is mined by drifting and a modified caving method. Some of the fluorspar appears to be of high fluxing purity. Hand picking is credited with the production of some acid fluorspar.

The Yandell mines include workings on a fissure of northeasterly bearing, which, however, is divergent from a minor to the Tabb system. The average bearing between the Yandell group and the Matthews, on the Tabb fissure, is N 70° E. The chief deposits, along the Tabb, have a footwall (south by east) of the Ste. Genevieve-St. Louis systems.

The Hodge System of Veins.

One and three-quarters miles northwest of Frances is found a group of mines on a system of fractures having a general northeasterly bearing. To this fault zone Ulrich (Prof. Paper 36) gives the name Hodge fault. The group includes the Reiter, Hodge, Loveless, Riley, Brown and Redd mines and prospects. The extension of the fault to the northeast or northwest from this group is not yet established; its demonstrated length is nearly two miles, along which several minor breaks are associated. The general strike direction of the Hodge fault system is considerably different from the Tabb system described above, being from N 50° E to N 55° E between numerous shafts. As noted elsewhere, it is characteristic that strike directions rotate easterly from western to eastern parts of the fluorspar field.

Hodge Mines.

Situated two and one-half miles south-southwest of View, on the John Hodge land. Operated by Crider and Myers.

The Hodge mines are among the oldest of the entire field. The deposits were first prospected in 1898, at which time gravel fluorspar was marketed. Later the mines became a part of the Kentucky Fluorspar holdings, and at present (1920) are operated under lease.

Exploitation of these mines has proceeded intermittently through many years, and abandoned shafts, pits, open-cuts, and trenches testify to the numerous periods of activity and quiescence. No deep shafts were sunk apparently, the deepest reported being 160 feet.

Present operations consist in the sinking of a 70 foot shaft on the site of an old shaft. At this point there are no solid walls, the shaft and drift being developed in residual limestone clay containing abundant limestone boulders. Perfectly solid walls probably appear at depths of about 100 feet. The walls are of Fredonia limestone.

Calcite is abundant; zinc blende and galena are also present.

The older workings have caved considerably, depressing the surface appreciably along the line of old drifts and shafts.

Loveless Mine.

One-third mile southwest of the Hodge mines, on the same system of fractures. Operated (1920) by the American Fluorspar Company, Peoria, Illinois.

The Ste. Genevieve limestone constitutes the footwall (southeast) and probably also the hanging wall, so that the displacement is probably within the thickness of that formation. Vein widths of fluorspar up to four feet are reported, with considerable calcite, especially along the footwall. The present shaft has a depth of 60 feet.

The fluorspar is apparently of good quality, white, and carries a small amount of galena.

Redd Mine.

Arnold and Bellamy, operators; situated about 4½ miles west of Mexico, and 3 miles southwest of View. Believed to be on the Hodge fault, but the fault has not been closely identified here; the Hodge system appears to involve several breaks, closely spaced in places, divergent in others, so that the mines described along this system may be located on several consanguineous fissures. At the Redd mine the underground workings were temporarily inaccessible; limestone appears in both walls, but at the top sandstone appears as boulders in southeast wall, while across the valley southeasterly the Chester series appears. The northwest wall (footwall) contains Ste. Genevieve limestone. Along the ridge on which the Redd mine is situated are indications of two or more fissures, one of which may indeed be the main Hodge fissure. The shaft is 50 feet deep, in the limestone wall. Little cross-cutting or drifting has yet been done. The vein matter at the surface washing plant showed white spar of apparently high quality, with some disseminated galena, and no zinc blende or barite; both of the latter are said to be wanting in the vein. No statement can be made regarding vein width.

Other prospects on the Hodge system include the Reiter, northeast of the Hodge mines; the Adams shaft, between the Hodge and Loveless mines the Brown property, between the Loveless and Redd; the Kirk prospect, southwest of the Redd mine and near Claylick Creek.

FAULTED ZONE WEST OF CLAYLICK CREEK.

At a distance of one to one and a quarter miles northwest of the Hodge fault system, and carrying a nearly parallel (slightly more northerly) general trend, a wide zone of faulting that has been much prospected carries mineral bodies through a length of about four miles. The two major faults of the zone are known locally as the Marion fault (west) and Woods fault (east), the two being but one-fourth to one-third of a mile apart in the vicinity of developments. The Marion fault is considered by Ulrich to extend from the Cumberland River on the southwest to an unknown terminal point east or northeast of Marion, making the total length about 15 miles. For a portion of this distance the fault follows a strong escarpment of Chester formations which constitute the hanging block (northwest) side. The Woods fault is given a less extensive course by Ulrich, and connects with the Marion fault through several cross-faults. Which of these actually is the more extensive and continuous, if either, through the Lucile mine at Marion it to be established. So far as the degree of mineralization is concerned, both appear to be parts of the same pronounced zone, some portions of which are strongly mineralized, while other portions are apparently barren of mineral, at least at the surface. A considerable distance along this zone between Marion and the Susie Beeler mine is devoid of prospects with any showing of fluorspar.

Mines and prospects along this fault zone include the Susie Beeler, Ebby Hodge, Riley, Butler, Howard, Farris, Giant, Cross, La Grange, Brown (Arnold and Bellamy).

Susie Beeler Mine.

Operated by Kentucky Fluorspar Company. Located about two miles west of View. The present shaft reaches to 180 feet, where a level has been started. At this depth solid walls, though not "tight," are met, and at the working face six feet of vein matter was disclosed. The limestone wall-vein contacts have been widened by the solvent action of percolating waters, and much of the original vein calcite has been removed. A small amount of barite was found in the decomposed portions of the vein. "Center slips" are prominent features. Zinc blende, galena, and a very slight amount of pyrite are among the vein minerals.

The mine is believed to be on the Marion fault of the Marion-Woods fault zone.

Leander White Mine.

This property of the Kentucky Fluorspar Company is situated about 2¼ miles N E of the Susie Beeler mine, and is believed to be on the same vein. Comparatively little prospecting has been done between the two mines. The mine is not now in operation. An old shaft reaches 90 feet; a new shaft sunk by the present owners reaches 140 feet. The walls of this mine both appear to be in the Chester series. Vein matter in surface piles shows wall rock-calcite breccia in abundance, carrying some fluorspar and a little galena.

Ebby Hodge Mine.

Leased (1920) by the Zinc-Spar Mining Company; not in operation; a prospect shaft on this property is situated about 300 feet S 40° W of the Susie Beeler mine shaft. The main workings are about one-third mile southwest of this shaft. Apparently it is on the same vein as the Susie Beeler mine.

Along a course of N 40° E a number of prospect openings show similar vein materials. Both zinc and lead ore minerals are present.

Prospects Southwest of Susie Beeler Mine.

Prospects along the course of the Marion-Woods faults, for a distance of three-quarters of a mile southwest of the Susie Beeler mine, include (1) the Cross shaft, 1200 feet from the Susie Beeler shaft; (2) the La Grange Mining Company prospect, 400 feet S 25° W of the Cross shaft; (3) an unknown prospect 600 feet south of the La Grange, where a quartzite-fluorspar breccia is in evidence, with coarse calcite and some zinc carbonate. The prospect appears to be on a minor fissure east of the main fault. (4) The Arnold and Bellamy prospect, on the Brown property, nearly 1000 feet south of (3), where an abandoned shaft 80 feet deep was sunk in quartzite; the vein minerals here include coarse calcite, fluorspar, galena, zinc blende; apparently also on an intersecting fracture of the main fault. (5) An unknown prospect showing quartzite breccia carrying fluorspar and galena in cracks; about 100 feet S 35° W of Arnold and Bellamy prospect.

Riley Mine.

This mine was being operated in 1920 by Riley and Larue, Salem, Kentucky. The property is situated on Claylick Creek, 3 miles west of Frances. It is believed to be on the Woods fault, though the identity is yet to be established; it is certainly on the Marion-Woods fault zone, and having a footwall of Ste. Genevieve limestone (southeast wall) with Chester sandstone and shale comprising the hanging wall, it is believed that the fissure at this mine is one of the major breaks of the zone. The mine is approximately three miles S 40° W of the Ebby Hodge mine.

A coarse calcite breccia is prominent in the vein matter. Considerable barite is reported to have been encountered in the residual clay blanket, but not found where solid walls prevail.

Other Prospects Near Riley Mine.

About one-half mile southwest of the Riley mine, and on fractures of the same system, are located the shallow workings of the Giant Mining Company (1920), and the Farris Fluorspar Company (1920). Neither have reached a productive stage of development.

At the Giant Mining Company shaft (not open since 1919) quartzite appears in the hanging (southeast) walls, and limestone (Ste. Genevieve?) in the footwall. Coarse calcite accompanies the fluorspar. Lead and zinc sulphides are present.

Farris Fluorspar Company Prospect.

This prospect, known as the Woods, is on a northeasterly dipping fissure, a few hundred feet east of the Giant Mining Company prospect, the veing of the latter dipping toward the Woods. An old shaft, 147 feet deep in the footwall limestone, is abandoned. A new prospect shaft has been opened 50 feet in clay, and 125 feet of drifting done along a N 40° E course (August, 1920). Quartzite appears in the hanging wall. Vein accessory minerals are very prominent calcite, some galena, and zinc blende.

5. Caldwell County District

In Caldwell County east and southeast of Fredonia, and north and northwest of Princeton, a belt of faulting has been prospected and mined to a minor degree for several decades, but without the development of any permanent mines. At the time of this investigation (July, 1922) no properties were being operated in this district.

Among the mines and prospects of earlier history in this district were the Marble, Senator, and Bright Mines, and the Lowery, Ray, Coleman, Satterfield and Tyrie prospects. At some of them barite was the mineral sought.

East of Fredonia the faults carry more easterly courses, rotating gradually to the southeast in the vicinity of Princeton. So far as yet discovered there are no evidences of extensive or intensive mineralization. The mineral associations are similar to the other districts already described. The mines and prospects are all situated upon faults which lie within or border an area in which are exposed the Ste. Genevieve-St. Louis limestones, as mapped by Ulrich, and here, indeed, would appear to be situated such veins as would give any promise of economic exploitation.

While barite is prominent at some of the prospects, i. e., the Lowery and Ray, 2½ miles east by north of Fredonia, and has been marketed in small amounts, it has always been obtained from the residual clays and not from solid veins carrying fluorspar. The mineral is not being produced at present.

The Caldwell County district flanks an area of strong mineralization with the probability that the degree of fluorspar concentration decreases through this district with increasing remoteness from the hypothetical central area of concentration, namely, the Mexico district.

Marble Mine.

Located 4½ miles east of Fredonia; not in operation. This mine is one of the oldest of the field, being first operated by the Marble family in 1875. The vein which was exploited at that time is reported to have been five feet in width, consisting of fluorspar and a small amount of lead and zinc sulphides. Calcite was also associated. The vein course is nearly east-west (N 85° E, underground, according to Fohs) with a slight southerly hade. The mine was not being operated when visited, but has recently (1920) shipped some fluorspar.

Senator Mine.

Five miles north-northwest of Princeton. Last worked in 1916 to a depth of 75 feet; reported vein width 2 feet.

Numerous prospect pits are associated along this vein. In earlier years a small amount of carbonate of zinc and galena were obtained, the greater reported vein width is that given by Ulrich and Smith (Prof. Paper 36), i. e., 465 feet, except at one point where the ore body widens to 15 feet, according to reports.

Lowery and Ray Barite Prospects.

At these pits 2½ miles east of Fredonia, nothing is to be seen but small waste pits containing barite. Fluorspar and calcite were entirely subordinate according to Smith (Prof. Paper 36).

Tyrie Prospects.

These prospects included several shafts and pits for a distance of one-half mile along a northwesterly bearing fissure system, four miles north of Princeton. At one of these, Hallowell property, considerable shallow depth mining has been done; one shaft is reported to be 100 feet deep; the usual association of mineral appears; both walls are limestone.

One-third mile east of the Hallowell shaft the Fraser shaft has been sunk, apparently on a different but closely associated fissure. Here the north wall is quartzite, the south wall contains boulders of limestone in residual clay. Calcite appears in the limestone; fluorspar, galena and zinc blende, and $ZnCO_3$ above water level, constitute the vein matter. It was worked for a short time in 1919 by J. R. Fraser.

Bright Mine.

Abandoned. Situated between the Senator mine and Hallowell shaft. Considerable coarse calcite appears in the waste pits; limestone forms one wall. Two shafts on this property about 150 feet apart have a bearing of N 85° W.

Other Prospects in Caldwell County.

Newkirk shaft, abandoned.

Union Mining Company, abandoned, old shaft 100 feet deep (?); limestone walls; fluorspar, calcite, galena, zinc blende.

Satterfield prospects; three and one-half miles south by west of Princeton.

6. Outlying Districts

Slight showings of fluorspar have been prospected in several widely scattered areas boarding the main fluorspar field from west to south.

Carrsville.

At Carrsville a small showing appears in the river bluff; three quarters of a mile southwest of the town, a shaft known historically as the Professor Wright shaft was sunk on a northeasterly bearing fault of northwesterly dip whose walls are of middle and upper Chester rocks (Weller, Golconda quadrangle, op. cit.) and the dislocation is relatively great. Some lead and zinc with very small amounts of fluorspar were obtained, but the deposit gave no promise of important vein widths and was abandoned. The location of this prospect is interestingly near the famous Fairview-Rosiclare developments on the Illinois side, but the stratigraphy appears to be unfavorable for the finding of a pronounced mineral body except possibly at a prohibitive depth.

Smithland.

Royal Mine. On the west side of the Cumberland River three miles northeast of Smithland, the Royal Mining Company has prospected a fault of doubtful value in the Middle Chester series. The fault as mapped by Ulrich has a northeasterly bearing and has a footwall (west) of Ste. Genevieve limestone. A 300 foot shaft has been sunk in the hanging wall. The quartzite is highly brecciated and contains thin purple fluorspar stringers. Coarse calcite is prominent. According to reports the operators had not succeeded in locating a large fluorspar body in 1916, and the work was stopped. On the same property several pits and old shafts lead to the nearby Old Silver Mine of historical interest, which was also known as the River Valley Mine, one of the oldest mines of the field. The mine was exploited for the silver bearing galena and proved unprofitable.

Klondike Mine.

Formerly known as Benard Mine. Last worked in June, 1920, by the North American Fluorspar Company. Situated six miles west by south of Salem, and about 6½ miles north by east of Smithland. A number of shafts have been sunk in the course of the mine's history; the present shafts reach depths of 80 and 165 feet, and are situated along a course N 25° E. An outcrop of the vein shows a course of N 35° E with a steep easterly dip. The west wall is Ste. Genevieve limestone; the east (hanging) Chester sandstone. The vein outcrop is sheeted and carries some disseminated galena.

Livingston County South of Cumberland River.

At several points south of the Cumberland River faults have been identified and slight showings of fluorspar are obtained, but at none of these places does there appear to be any promising amount of mineral. They have been only slightly prospected. Their location rather far outlying in the flanks of the proven districts militates against any probable economic value.

Lyon, Trigg, and Christian Counties.

In all three of these counties very slight showings of fluorspar have been prospected without any success, and the discovery of important deposits at workable depths is scarcely to be hoped for owing to their remoteness from the probable centers of mineralization.

CHAPTER VIII.

MINING, MILLING, AND PROSPECTING

Mining

General Remarks.

Throughout the entire fluorspar district countless abandoned shafts and pits indicate an enormous aggregate expenditure in the attempts to exploit deposits and develop paying mines. In most cases, however, the intention seems to have been to obtain immediate production instead of attempting to methodically develop permanent mines. In earlier years, also, a few of the veins were exploited for zinc values, in which case the associated fluorspar became a more or less successful by-product. Zinc mining failed, in one case because of the complete exhaustion of the ore body, and in most of the other cases because of the lack of sufficient concentration of the zinc ore mineral to allow these mines to compete in the market with other zinc districts where the deposits were richer. It is not believed that the fluorspar district can also become a zinc producing territory, except insofar as methods of concentration by milling allow the recovery of zinc values as a by-product of the fluorspar industry.

In many cases the methods of mining employed were not conducive to the establishment of permanent mines. Frequently, as little care was taken in the initial stages of the operations, the mine workings were unsuited to long-continued operations. Shallow depth and surface methods in clay are characteristic of the district because, as pointed out in Chapter 5, the more valuable deposits are situated in limestone terranes many of which have been subjected to deep residual decay. Such ground is, of course, easily worked from the surface, and does not require expensive installations while the exploitation of the solid veins requires a considerably greater initial expenditure and development before profit may be realized.

Veins.

The exploitation of a vein is commenced with the sinking of a permanent shaft in the footwall, if the vein is nearly vertical, and in the hanging wall if the vein hades appreciably. In former years shafts were frequently sunk upon the vein, following the vein matter along the footwall. Examples of such inclines are to be seen at the abandoned Memphis and Nancy Hanks mines. Inclines to shallow depths are sometimes sunk during the early development stage of a prospect, but the practice is not universal. Owing to the relative weakness of vein matter for supporting purposes, the frequently shattered condition of the hanging wall, the variability of dips in most veins, the complications and loss of time which arise in hoisting through inclines, and the increased expense and difficulty in timbering and maintenance, the sinking of such shafts is inadvisable from the standpoint of engineering economy.

The choice of site for a shaft is chiefly determined by two considerations. The first of these, as indicated above, is the attitude of the vein. Where the hade of the vein is 5 degrees or less the shaft is generally sunk in the footwall if this work is otherwise favorable; the crosscut at the 500 foot level for a vein carrying 5 degrees constant hade (85 degree dip) would be approximately 60 feet at the surface, while for a vein hading 15 degrees (dipping 75 degrees) the crosscut at this level would be nearly 150 in length. The increased lengths of crosscuts of deeper levels with veins of relatively great hades makes it advisable in such cases to sink the shaft in the hanging wall, piercing the vein at an intermediate level and thus lowering the cost of primary development and of haulage. Another factor in the choice of shaft site is the character of the hanging wall rock. Where this is of soft, thinly bedded, or highly brecciated material, a position in the footwall is sometimes considered preferable, balancing the cost of more extensive crosscutting against the increased maintenance of a hanging wall site. Where limestones of the Ste. Genevieve-St. Louis series comprise the hanging wall it is to be considered advisable to sink in this wall for veins hading 5° or more where development is planned to depths of 500 feet or greater, inasmuch as these limestones though more highly fractured in the hanging wall position than in the footwall practically always afford satisfactory shaft sites.

The great depth to which residual decomposition affects the limestone formations producing a thick clay overburden makes it necessary to completely line the shaft to a depth somewhat below the top of the undecomposed wall rock. In a few cases (example, Ada Florence mine) a reinforced concrete collar and shaft lining to a shallow depth is constructed, insuring permanency, relatively low cost of maintenance and tightness. Usually close lagging with boards or cribbing with timbers is practiced. In not a few mines and prospects, the employment of light lagging constitutes a hazard which should be avoided. The difficulty of holding a shaft in clay ground is fully appreciated; it certainly cannot be done safely with ordinary boards.

(26) A method in remining caved ground, at Susie Beeler mine.

As the shaft sinking progresses to depths suitable for the development of stopes, working levels are established through the driving of crosscuts and drifts. Crosscutting from the shaft to the vein constitutes "dead" work and it is desired to keep these excavations as short as possible, so that knowledge of the average vein dip is important. When the vein is reached the crosscut is carried to the opposite wall, and a drift is then driven along the vein in one or both directions. Along the drift, at intervals depending upon the variability in vein width, short raises are excavated preparatory to stoping.

Overhand stoping methods are usually employed except where exceptionally rich vein matter makes it desirable to resort to underhand stoping at the drift floor. Overhand stopes are carried to within 10 to 25 feet of the next drift above; in some cases the quality or width of the vein makes it advantageous, even at the expense of considerable extra timbering, to carry the stope entirely through to the upper drift, and to bridge with timbers the excavation thus made in the upper drift floor. Shrinkage stoping is the common practice; the excavated stope is thus kept filled with waste and ore to a working level in the stope. Numerous short raises along the drift serve as bins for loading buckets or cars, sufficient material being drawn each day in an active stope to maintain a working level at the stope face and roof. The filling material also serves for support of the workings, but upon a complete removal of the material from the stope, heavy timbering is frequently necessary if the excavation is to be maintained.

The distance between levels is not standardized. At the larger mines levels at 100 foot intervals are believed to be good practice; especially is this true where long "pinchs" of the vein may be encountered and considered "dead" work along drifts made necessary. For permanent mining at depths below 300 feet, smaller intervals are inadvisable. In the earlier stages of development levels have usually been established at distances of 50 to 75 feet. In several instances this procedure has resulted in a considerable amount of uneconomical mining; ordinarily it is largely to be attributed to intermittent mining by numerous operators. Thus at the Keystone Fluorspar Mine (Blue and Marble mine) at Mexico, fourteen levels are said to have been worked within a depth of 200 feet.

In drifting, walls of Ste. Genevieve-St. Louis limestones and of the thicker bedded quartzitized sandstones are firm and require very little timbering, provided sufficient pillar material is left at the drift floor. Walls of the thinly bedded sandstones, shaly sandstones, and shales are usually highly brecciated and dragged, requiring systematic timbering.

One of the mining difficulties where limestone walls prevail is in successfully dealing with "mud runs." Along a limestone wall, especially at the contact with vein material, and also particularly along the hanging walls of upper levels, downward circulating ground waters have enlarged the wall fissures and contacts by solution, often developing cavities of considerable extent. Such cavities become filled with mud by infiltration. Inasmuch as they are common in fractured wall rocks adjoining vein matter, mining operations frequently penetrate such mud reservoirs allowing the slime to rush into stope and drift. These cannot usually be foreseen. Nothing remedial can be done, except probably at prohibitive expense. The tapping of a pocket, often containing many tons of mud, entails considerable expense of removal.

Superficial Deposits.

The superficial or "gravel" deposits are mined by open-cut methods to depths of 20 to 30, rarely to 50 feet; at greater depths, shaft and drift mining is employed. Where the deposit is somewhat extended laterally, by creeps and settling of the unconsolidated clay walls, a system of caving may be used, as at the Susie Beeler, Yandell, and Pogue mines, Mexico-Claylick district. The widest portion of these deposits reported in 1920 was 36 feet, and since solid wall rocks were absent, the fluorspar being somewhat spread out and dispersed through clay-sand overburden, they were especially adapted to this system of mining. In brief the operations consist in drifting along and in the deposits, preferably at one side, working laterally to the limits of the deposit, withdrawing support, and allowing overlying material to cave, after which caved material is removed and drifting operations are continued. This method is more hazardous than others, and timbering is costly. The overburden slowly settles from the surface down, so that when carried on close to the shaft the surface plant may eventually be seriously disturbed. The only alternative to this method is to drift and stope in the usual fashion, giving permanent support to the underground excavations by heavy timbering with square sets and lagging. With deposits of the widths met with in the Yandell and Pogue mine, such maintenance of excavation seems to be not economically feasible. The deposits should not be mined by caving within a radius of the order of a hundred feet from the shaft, otherwise the service and safety of the shafts become greatly impaired.

Care and Safety in Mining.

Generally speaking, the operators in the fluorspar field exercise a reasonable degree of care in mining to prevent accidents. There should be, however, closer supervision with inspection by competent state officers looking to the establishment and maintenance of safety rules. Chiefly in need of such inspection are equipment and operations relating to the hoisting of men, the maintenance of shafts, working drifts, and stopes in mines when perfectly solid walls are not present, and ventilation in the prospects on superficial deposits. The employment of old and worn hoisting cable, insufficient and light timbering and logging in shafts, especially when passing through clay overburden, the lack of ladderways in shafts, and the crowding of men onto a hoisting bucket constitute particular hazards. In a few cases the shaft sizes are insufficient. Ventilation is generally good except in shallow prospect shafts and associated drifts in superficial deposits. Well established mines should possess at least two shaftways through both of which access may be made along ladder ways and which will, further, insure good ventilation. Continuous vertical ladder ways should be avoided.

Milling

The operations of milling are generally simple, consisting chiefly of washing gravel fluorspar, or crushing and concentrating by jigs and tables to produce a marketable fluorspar (of primary importance), and a lead or zinc concentrate (of secondary importance).

Preparation of Gravel Fluorspar for the Market.

The mined material from a shallow depth superficial deposit rarely contains much calcite or metallic sulphides. Seeping ground waters have generally dissolved the originally associated calcite, in the same manner that the chemically similar limestone walls are decomposed and the $CaCO_3$ removed in solution; during this process, too, the zinc, largely or wholly changed to carbonate, is more or less completely removed, while the lead sulphide is affected slightly along similar lines, but in large part tends to remain as galena in the "gravel" fluorspar, from which it can be removed, after washing, by handpicking. Thus the "gravel spar" of superficial deposits contains as chief impurity the red clay residuum from limestone wall rock decomposition; minor impurities are silicious rock fragments from sandstone and shale wall materials. As mining proceeds more deeply in these deposits calcite appears and increases (when an original vein mineral). As permanent ground water level is reached, the deposits merge, of course, into the solid vein type, with the normal assemblage of associated minerals.

In a few of the superficial deposits, especially in places along the Tabb, Marion, and Woods systems, Mexico district, in

(27) Type of log washer generally used for cleaning gravel fluorspar, at Two Brothers (formerly Watson) mine, Salem district.

the Fredonia-Princeton district, and in the northern part of the Lola district, barite appears in detrimental quantities. The presence of this mineral necessitates careful milling.

Ordinarily, therefore, in the absence of barite, "gravel fluorspar" requires only washing to remove adhering clay. This is accomplished with log-washers; during the charging and operating of the washer, silicious fragments, and galena are removed by hand culling. The product is then ready for market. Indeed, a high quality of fluxing spar may be obtained by this simple operation.

Systematic Milling.

The chief object of systematic milling is to produce marketable fluorspar as free as possible from contamination with lead, zinc, silica, and barite. The products of systematic milling operations comprise:

(1) Highest grade acid fluorspar, lump and ground, 98% CaF_2; less than 0.5% silica.

(2) Fluxing spar, either coarse lumps or gravel; 85% CaF_2 or better, and 5% (or less) silica.

(3) Fluxing spar, coarse lumps or gravel, 85% CaF_2, 6% silica.

(4) Low grade fluxing spar, coarse lump or gravel; less than 85% CaF_2, over 5% silica, according to trade acceptances.

Products of quality intermediate between (1), (2), and (3), and may be marketed as the next lower grade, or guaranteed at intermediate grades according to contract.

The chief milling difficulties are separation of fluorspar and zinc blende into marketable products of both, the removal of barite, and the removal of silica. The separations of calcite from fluorspar, and of galena from both are sufficiently attained in the common type of mill which includes coarse-breaking, hand-sorting, crushing, screening, jigging (in Joplin jigs), and tabling. When zinc blende and barite are absent very little difficulty is experienced in cleaning both galena and fluorspar products. By the use of jigs of several compartments and the cleaning of fluorspar from the lower compartment at intervals, or better by carrying the fluorspar calcite-tailings to other jigs marketable lead concentrates and gravel fluorspar can be obtained. By sacrificing quality of lead concentrates through jigging and tabling operations a fluorspar product of acid quality may be obtained, as at the Liberty Bond Mill (Eagle Fluorspar Company, Salem). Zinc bearing "ores" do not readily lend themselves to hydraulic concentrating methods for the recovery of marketable fluorspar and zinc concentrates. Appreciable contamination of either of these minerals by the other makes an unmarketable product; in milling for a fluorspar product much of this mineral is necessarily lost with the unmarketable zinc product. By flotation a good zinc concentrate may be made, the remaining fluorspar tailing being contaminated with zinc. Flotation, though a successful process in saving zinc, therefore causes a loss of fluorspar and necessitates a secondary installation. Zinc and lead bearing fluorspar when treated on concentrating tables (such as Deister, Wilfley, etc.) allow the ready recovery of good lead concentrate, fluxing fluorspar, and unmarketable fluorspar-zinc middlings. The middlings can therefore be secondarily treated by flotation for the recovery of marketable zinc concentrate. The presence of barite offers a further complication inasmuch as the mineral cannot be

(28) Fluorspar storage and loading yard, on Illinois Central R. R. at Mexico.

allowed even in small percentages in the final lead or fluorspar products. Barytic materials require very close mill adjustments and, usually, remilling of products. Silica is present in two forms, as included silicious rock fragments and as microcrystalline quartz intimately associated with the fluorspar and sulphides (particularly zinc). The rock fragments are easily removed in milling, going into mill tailings with calcite, both from jigs and tables. Microcrystalline quartz has been shown in an earlier chapter to be so complexly intergrown with fluorspar, as to prevent separation of the two even by preparatory fine grinding. It is to be emphasized again that numerous samples which contained zinc were found by microscopic analysis to contain the microcrystalline quartz.

Attention should be directed at this point to recent research by the U. S. Bureau of Mines on fluorspar from southern Illinois which contained the following minerals:

Lead	7.3%
Zinc	27.9%
Fluorspar	35.7%
Silicia	9.5%
Calcite	4.7%

By the application of an inexpensive copper sulphate treatment, followed by drying and electrostatic separation, it was clearly demonstrated that both zinc blende and fluorspar concentrates of marketable quality can be obtained. The tests showed the producing of fluorspar concentrate above acid quality (98.7%), although nearly 35% of the fluorspar apparently went into an unmarketable zinc-fluorspar tailing. Flotation tests on the same ore gave a marketable zinc concentrate; a marketable fluorspar product can be made, however, it is pointed out, only by a previous table concentration to remove calcite and silica. In conclusion it is pointed out that a "marketable spar can be obtained by flotation only by sacrificing a large amount with the silica and the calcite discarded on the tables, while practically any grade of spar can be obtained electrostatically."[1]

Nearly two decades ago, an attempt was made to separate zinc blende and fluorspar by fine crushing and pneumatic concentration. Several groups of sizing apparatus (to 180 mesh silk bolting cloth), and Hooper pneumatic concentration were installed at the Evening Star plant near Salem. The process was unsatisfactory and costly.

The mill flow sheets given below were in practice in August, 1920. Changes are frequently made as experimentation indicates the way to better methods, accordingly some of the flow sheets may be modified by the time of publication of this bulletin.

[1] This digest and quotation are taken from the following paper: Bureau of Mines, Dept. of Interior; Reports of Investigation, Serial No. 2261, the separation of sphalerite, silica, and calcite from fluorspar, by John Gross, Metallurgist, July, 1921.

The noteworthy mills in the fluorspar field are as follows:

Kentucky Fluorspar Company, at Marion.
Gugenheim Mining Company, the Lucile Mine, at Marion.
Franklin Mill, Fairview Fluorspar Company, at Franklin Mine.
Aluminum Ore Company, at Haffaw Mine, Mexico.
Keystone Fluorspar Company, at Blue and Marble Mine, Mexico.
Eagle Fluorspar Company, at Liberty Bond Mine, near Salem.
American Fluorspar Company, at Hudson Mine, near Salem, in construction.

Of these the mills of the Kentucky Fluorspar Company, Gugenheim Mining Company, and American Fluorspar Com-

(29) Custom Mill, Kentucky Fluorspar Co., at Marion.

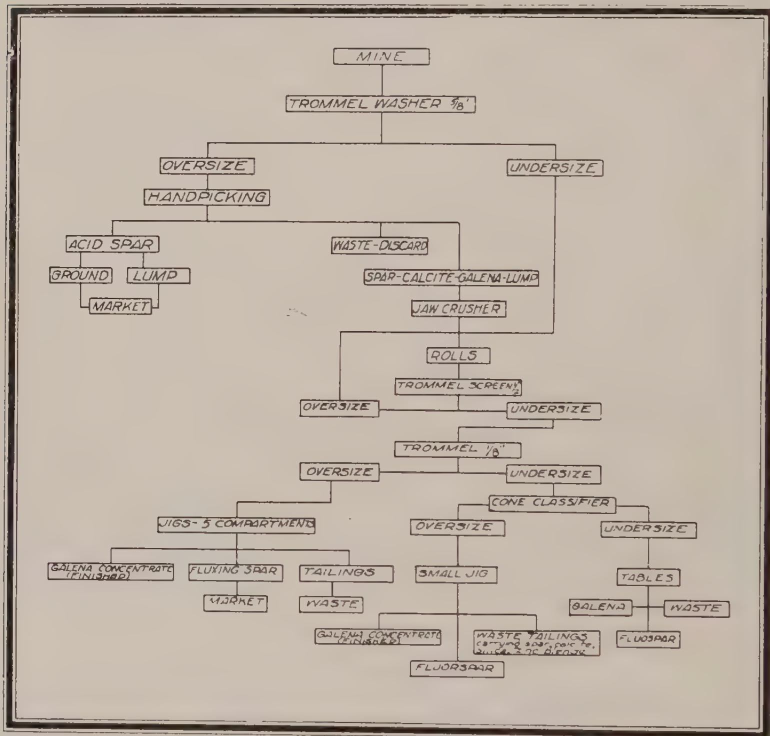
pany do custom milling. The first four mills of the above are the most extensive and elaborate. It is seen that the vast majority of mines are not provided with milling facilities other than log-washers. Ores from such sources are in part commercial with no treatment and in part are carried to the few custom mills. Ores may either be sold outright to the milling companies or treated at the custom mills on a contract or tonnage basis.

Franklin Mill Flow Sheet.

At this mill acid quality lump spar is removed by hand picking, the ore being washed through a trommel and passing along a slow moving belt from which pickers separate the lumps of various grades. See figure 30.

Gugenheim Mining Co.

At the mill of the Lucile mine the process of treatment is essentially like that at the Franklin mill but less extensive. Jigs and Deister tables are used. But one sizing trommel is



(30) Flow sheet at Franklin mill.

used giving two undersizes, which go to Jigs and Deister tables. Oversize is returned, through rolls, to trommel.

Kentucky Fluorspar Co.

The essential operations at this mill are illustrated by figure 31.

Keystone Fluorspar Co., Mexico.

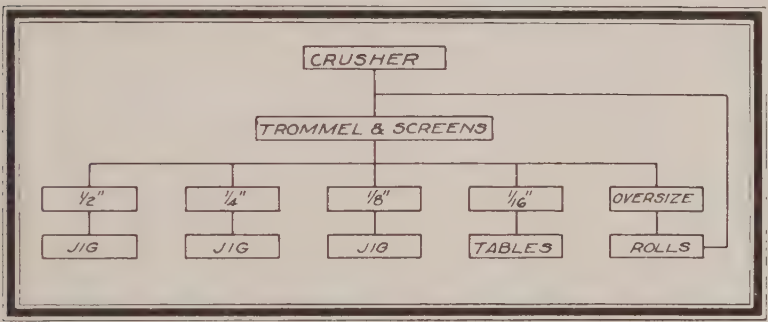
The mill of this company, at the Blue and Marble Mine, is similar to that of the Kentucky Fluorspar Co., but screens to three sizes instead of four, viz., 1/2″ to 1/4″; 1/4″ to 1/16″; 1/16″ to 0. The first two sizes go to jigs, the last size goes to tables.

Aluminum Ore Co., Mexico.

At the Haffaw mine the operations involved closer sizing in the jigs. The essentials of the flow sheet are shown in figure 32.

Eagle Fluorspar Company, Salem.

The operations at this mill are directed chiefly toward the production of acid grade fluorspar. A very high grade product is obtained, but apparently at the expense of obtaining a poorer grade galena concentrate, and with higher losses of fluorspar in the mill tailings. The success in producing particularly clean



(31) Milling sizes at the Kentucky Fluorspar Co., mill, Marion.

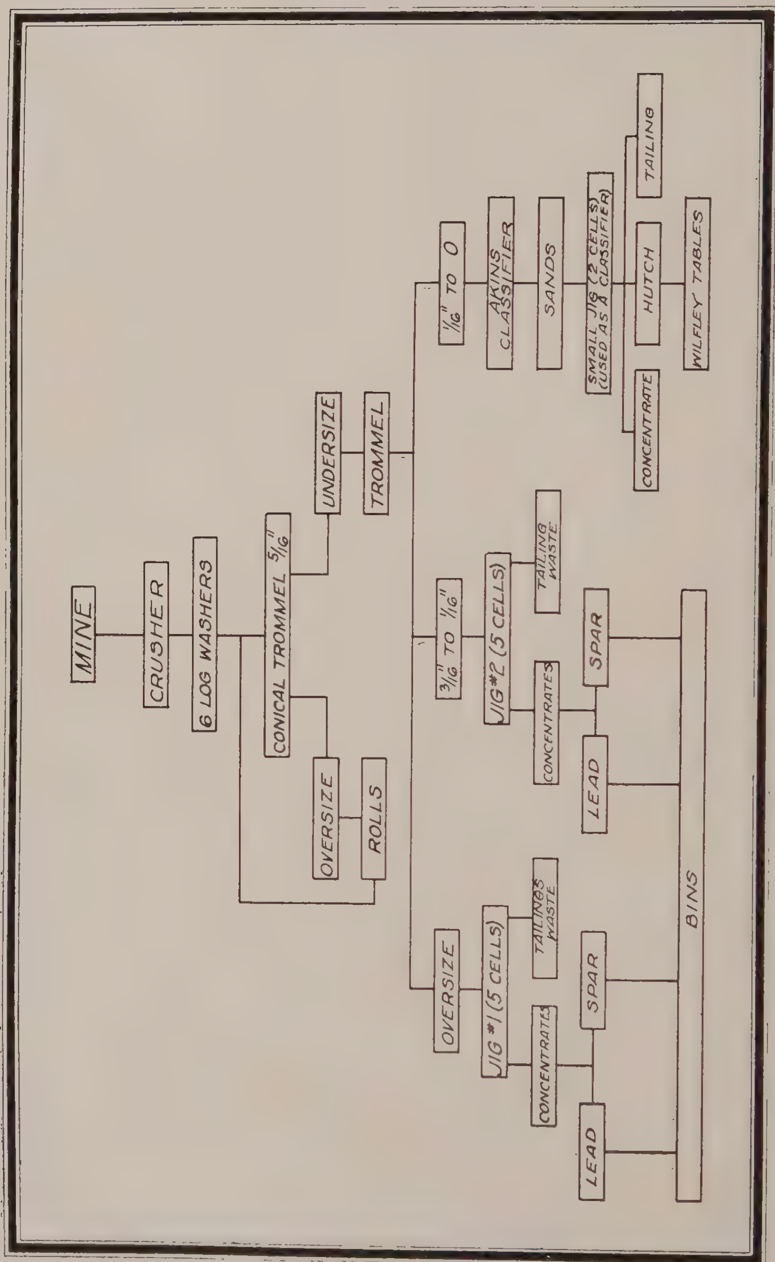
fluorspar is greatly assisted by the absence of zinc blende and of large amounts of calcite. The mill flow sheet includes a crusher, rolls, log washer, screens, a jig, and table.

North American Fluorspar Company.

At the Hudson mine, the mill plant was in process of construction so that no details of the methods employed can be given.

Prospecting

Since all deposits of proven value in Kentucky occur in fault fissures, it is of prime importance in prospecting for new deposits to discover the position of outcrop of a fault whether or not mineral be found. Neither the finding of gravel fluorspar nor the discovery of a fault may be considered as indicating the presence of economic mineral bodies, however, inasmuch as



(32) Operations of milling at the Haffaw mine, Mexico.

many faults, probably the majority indeed, are unmineralized, while many others carry veins too narrow for exploitation. Superficial deposits are frequently greatly concentrated above solid rock depths, and may prove economical only above solid walls, becoming too narrow for successful working with the transition to solid vein matter.

The location of a fault may be recognized in the field where two unlike rock formations appear in juxtaposition, the plane of separation is then the fault fissure; thus on opposite sides of a fault the rock strata becomes discontinuous at the fault plane. The recognition is easy where the formations on the two sides of the fault are of different rock species, such as limestone and sandstone, limestone and shale, or sandstone and shale. The recognition is sometimes difficult when similar rocks appear in both walls, such as St. Louis limestone opposite Fredonia limestone, Upper Fredonia limestone opposite Lower Fredonia, Sandstone (quartzite) opposite sandstone, etc. In such cases it can usually be observed that the apparently similar rocks differ markedly in textures or other details, that horizontal bedding or jointing planes of one are not continuous across the fissures with similar features of the opposite wall rock.

In the absence of rock outcrops the presence of a fault may be very difficult to ascertain. A clue is sometimes afforded by the sudden appearance of red clay soil in horizontal continuation of an area underlain by sandy soil.

A highly fractured condition of a rock outcrop, particularly when more or less "sheeted" by roughly parallel fractures may indicate the presence of a fault. Such rock masses usually also show "dragging," or steeply dipping bedding and bedding joint planes. The sandstone and shale walls of faults display this feature markedly.

The pronounced degree to which sandstone walls have been silicified or "quartzitized" along some faults has led to the development of quartzite ridges or "reefs" due to the superior resistance of these rocks toward erosian forces. Ridges of this nature may therefore indicate the presence of a fault fissure; especially will it be true that sandstone escarpments along faults possess steep slopes along the fault side and comparatively broad slopes away from the fault position.

Other features being of equal value faults in terranes underlain by limestone of the Ste. Genevieve-St. Louis series are considered most favorable prospecting grounds. It is believed that such rocks, due to their chemical character and stratigraphic positions were more susceptible to mineralization. Therefore it becomes important for the prospector to identify these formations.

Calcite vein matter, with or without associated fluorspar, may be generally considered as favorable, and will warrant conservative testing by pitting or shallow shaft sinking. Calcite vein filling may give place to fluorspar in any direction along a vein. Calcite appears more abundantly in veins whose walls are in part of the Ste. Genevieve-St. Louis formations.

Both walls of rocks other than limestone are not generally to be considered promising, although it should be remembered that the character of the walls changes with depth. It therefore becomes of importance for the prospector to identify the particular sandstone or shale formations that appear at the surface in order to calculate the depth to more favorable horizons.

When the opposing sides of the fault are similar the fault frequently cannot be readily determined and technical advice must be sought.

In general, shallow trenching and pitting is recommended as a first step in the exploitation of a deposit, in order to establish the true vein position and trend. Trenches across the deposit may be cut at hundred foot intervals along the supposed course. If possible pitting should be carried to a depth where at least one of the solid walls appear. When this is impracticable a shaft may be started on the gravel fluorspar, at its apparently most favorable point. Sinking should be continued until it either passes into solid vein matter, or until the "gravel" fluorspar passes entirely out of the excavation; in the latter event sinking may be profitably continued a short distance and followed by crosscutting in the direction in which fluorspar appears to have left the shaft. This procedure allows the prospector to ascertain the direction in which the true vein may be found, by reason of having passed through such "washing" of the vein as may have been brought about by down-slope creep. Crosscutting as above should then pick up vein matter again, indicating the position of the hanging and footwall sides. Sinking and crosscutting should be continued until the size, quality and attitude of the vein are well indicated, after which plans may be made for permanent development. The length as well as the width and quality of the vein should be reasonably assured before a permanent shaft, levels, and stopes are contemplated. Always it should be borne in mind that an economic body of "gravel" fluorspar does not prove the presence of an economic solid vein.

(33) Operating prospect shaft with hand windlass. Breaking ground on Jones vein. Holly Ore and Mining Co.

Prospecting for vein extensions or for new veins by means of diamond drilling has been quite extensively practiced in the Illinois field by three companies. The method has not been utilized in Kentucky, partly because of the great expense involved and partly because of skepticism as to its efficiency. Diamond drilling is indeed costly and therefore adapted only to very extensive prospecting. It is not recommended for operators having but small capital, inasmuch as the method may involve the drilling of numerous holes to satisfactorily prospect a supposed vein. The objection is made that the diamond drill may happen to pass through a pinch and thus fail to register the presence of possibly great mineralization. The objection is invalidated when numerous tests are made at uniform intervals. It is also stated that fluorspar does not "core" so that its presence may not be noted in drilling. With proper care in drilling, however, it appears that cores of fluorspar can be well preserved, though it is to be admitted that there is some danger of registering too heavily if the proper precautions are not taken. Finally core-drilling establishes the stratigraphy without any doubt whatever.

In diamond drilling the holes should be started well away from the vein, the distance to be calculated by the depth at which it is expected that the vein will be pierced. The holes should be inclined at 45°. Topography sometimes assists in that a hillside site for drilling may shorten considerably the length of the drill hole. Within a mine level the drilling of horizontal holes laterally from a lower drift may disclose associated or parallel veins. The method has been used in the Illinois district for the purpose of exploring the ground between two veins already developed.

CHAPTER IX.

THE CENTRAL KENTUCKY FLUORSPAR DISTRICT

Introduction

The field investigation in the Central Kentucky district was conducted in the summer of 1921. No attempt is made to describe the veins and mines in detail inasmuch as the mines were idle at the time and only a few openings were accessible. The purpose of this chapter is merely to present a general description and discussion of the district, and to indicate its present state of development. The field merits closer study than it has been possible to undertake.

Location

Commercial deposits of fluorspar are mined in Mercer and Woodford counties. The producing area is small, and is confined to the bluffs of the Kentucky River for a distance of about three miles extending north-northwesterly from Mundy's Landing. This ferry point is situated approximately twenty miles southwest of Lexington. The nearest railroad shipping point is at High Bridge, slightly more than two miles to the southeast of Mundy's Landing, but the Kentucky River is navigable for river barges and makes shipment to Frankfort a more satisfactory means of transportation.

Physiography and Culture

The district lies nearly centrally within the famous Bluegrass region. The upland topography is gently rolling without sharply accentuated knobs and steep ravines. Into this plateau of rather low relief the major streams and tributaries have incised steep-walled valleys. Chief among these is the Kentucky River which bluffs rise steeply a vertical distance of 250 to 300 feet. The uplands contain numerous shallow depressions known as "sink-holes," corresponding to an early stage in the development of karst topography.

This portion of the State is devoted essentially to agriculture due to the favorable topography and rich soil. The region is well settled, has numerous progressive and flourishing large towns and villages, and is crossed by several important railroad lines.[1]

GENERAL GEOLOGY.

The bed-rock of the district consists of nearly horizontal thick layers of Ordovician limestone. Shale and sandstone formations are wanting, but are to be reached by drilling below the lowest exposed bed known in the district. The limestones are light gray to buff in color, partly crystalline, and contain some fossil remains.

The formation in which the exposed commercial veins of fluorspar occur is the High Bridge, which, according to Professor Miller, consists of three members designated by him as follows:

Tyrone	90 feet
Oregon	15 to 25 feet
Camp Nelson	285 feet

The Camp Nelson is the oldest exposed bed in Kentucky. Along the portion of the Kentucky River that crosses the fluorspar area the Camp Nelson limestone is exposed to thicknesses between 75 and 100 feet, so that the upper portions of the veins are above the Tyrone member (in the Lexington formation), while the lower portions have walls of Tyrone, Oregon, and Camp Nelson limestones. The base of the Camp Nelson limestone may be at a depth between 375 and 400 feet below the river in the vicinity of Mundy's Landing if the thickness of the High Bridge formation, as indicated at Camp Nelson, continues toward the northwest. Thus, so far as wall-rocks are concerned, the vein walls will change at a depth below river level approaching 400 feet unless the formation proves ultimately to be markedly irregular in thickness.

Absence of Igneous Rocks.

Unlike the western Kentucky fluorspar district this field has no exposed igneous rock bodies. The nearest known expos-

[1] For further details the reader is referred to the interesting and scholarly volume "The Geology of Kentucky," by Dr. A. M. Miller; Kentucky Geological Survey, Bulletin 2, Series V, 1919.

ures of this sort of material are in Elliott County, some 150 miles to the east, where a few peridotite dikes have been found. They cannot, in the present state of knowledge, be logically connected in any genetic way with the fluorspar veins of the district under consideration.

Attitude of Rocks.

While the limestone beds have a nearly horizontal attitude, there is, nevertheless, a slight general and distinct dip in a northwesterly direction. According to Professor Miller [2] this amounts to 18 feet per mile in a direction N 45° W. This dip is apparently due to the position of the area upon a broad domal uplift along the general course of the Cincinnati geanticline, or "arch." The district is nearly centrally located upon this structure, the axis of the arch being nine or ten miles east of Mundy's Landing. The arch has resulted in the present exposure of rocks of the Ordovician series, stratigraphically much lower than the series exposed in western Kentucky.

Faults.

The central Kentucky field stands again in marked contrast with the western field in the absence of localized areas of pronounced normal faulting that are so characteristic of the western district. Faulting has occurred in central Kentucky, indeed, but here it is expressed in a few long belts each carrying a small number of related faults instead of in wide areas carrying numerous intersecting and comparatively short faults. Near the fluorspar bearing portion of the Bluegrass two distinct belts are reported and described by Professor Miller.[3] The key map, Fig. 1, shows their location and general trend. The Kentucky River Fault Zone is reported to be the larger and to consist in places of two breaks. Maximum throw is given 350 feet and the total length traced on the surface about fifty miles. The second, known as the West Hickman Fault, runs with a northeasterly course for about 25 miles from a point a short distance east of Nicholasville (Union Mills).

These faults are somewhat remote, however, from the developed fluorspar veins and no structural or genetic connection

[2] Op. cit.
[3] Op. cit., pp. 233-236.

between these two types of geologic phenomena in this field can be safely postulated. The nearest approach of either of these fault zones to the eastern edge of the fluorspar area is about nine miles.

It is believed probable that the faulting may have accompanied the Appalachian Revolution at the end of the Paleozoic era, in which case it would be considered as the effect of mountain-building, a crustal disturbance of great extent, rather than as the concomitant of local crustal adjustment to deep-seated igneous activity.

Mineral Veins in Central Kentucky.

Narrow veins are numerous throughout the broad Bluegrass region. They are of several types, according to the mineral constituents, as reported by Professor Miller:[4]

1. Calcite.
2. Barite-sphalerite-galena.
3. Barite-galena.
4. Barite-sphalerite.
5. Barite.
6. Barite-sphalerite-calcite-fluorite.
7. Fluorite-sphalerite-calcite.
8. Fluorite-calcite-barite.
9. Barite-calcite-sphalerite.
10. Barite-galena-strontianite.
11. Barite-calcite-sphalerite-galena.

In all cases the veins are found outcropping only in areas underlain by the Ordovician limestones and are not found between walls of sandstone or shale. The lowest exposed strata are limestones of middle Ordovician age, in which some of the veins are exposed along the deeply incised valley of the Kentucky River. The mineralogic aspects of some veins appear to change vertically with passage change of into walls to other stratigraphic units. Thus, Professor Miller says of the Shryock Ferry vein: "As long as the vein is in the Tyrone limestone its content is mainly calcite with some sphalerite; when in the Lexington limestone it is barite with little calcite or sphalerite." The

[4] For a general treatment of mineral veins in Central Kentucky see A. M. Miller, The Lead and Zinc Bearing Rocks of Central Kentucky: Kentucky Geological Survey, Bulletin 2, 1905; also same writer, The Geology of Kentucky (op. cit.)

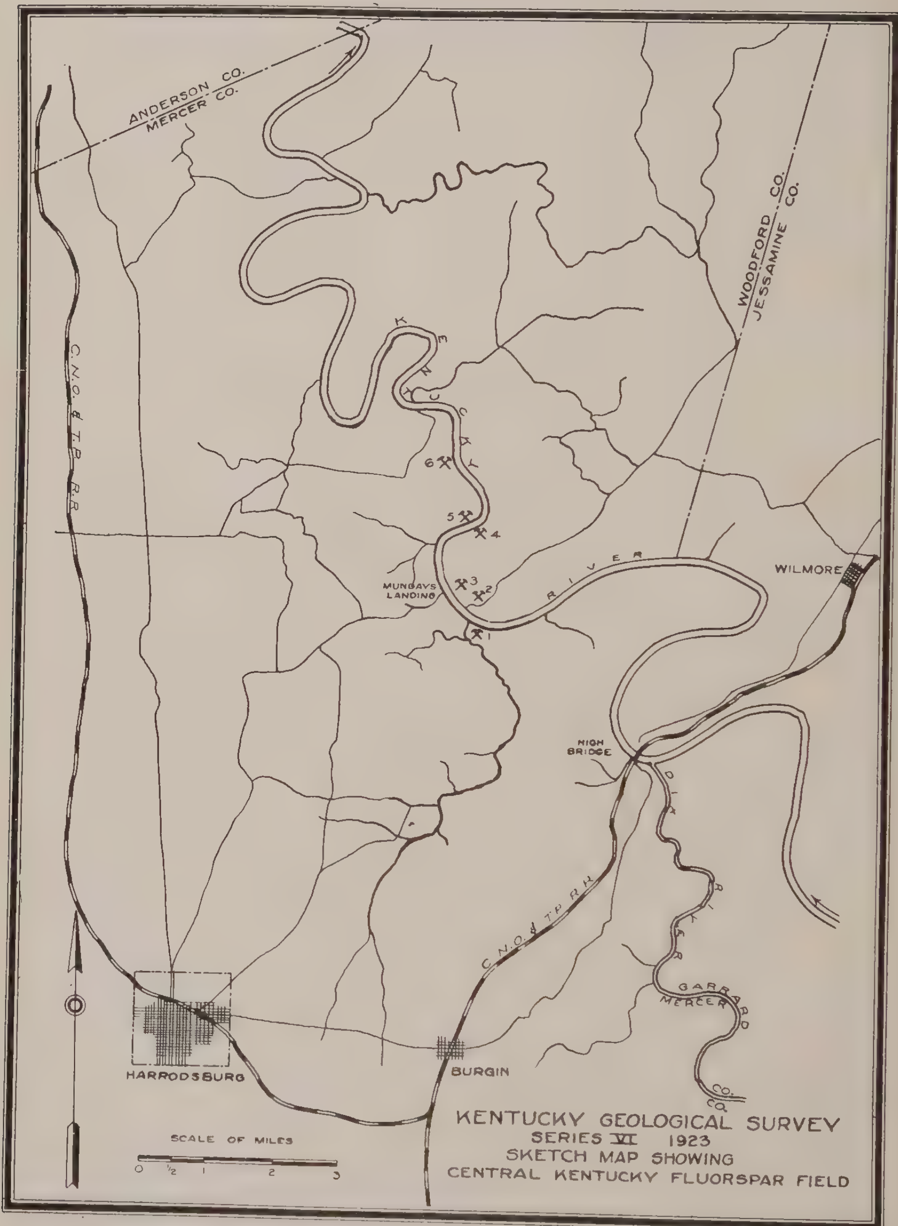
same authority also remarks to the effect that veins in the Trenton carry predominating barite and are also generally richer in the lead and zinc minerals, while the veins of the High Bridge areas are predominantly calcite and fluorite bearing. Such stratigraphic correlation of vein material would rather suggest that the veins were deposited from ground waters of meteoric origin and shallow depth circulation. With the exception of the mineral fluorite, possibly, these mineral associations are common to deposits whose origin has been attributed to waters of meteoric origin (surface waters descending into and circulating in regional bed-rock, at and below ground water level, but limited to relatively shallow depths). These minerals are frequently concentrated from the surrounding rocks.[5]

As stated above, the more barytic veins are reported to occur in the Trenton (Lexington formation of central Kentucky), overlying the High Bridge, while in the latter are found the fluorite-calcite veins. Barite is, however, also an appreciable gangue mineral of the worked fluorite-calcite veins, so that, while the stratigraphic distinction may be true in a general way the minerals are not closely confined to either of these limestone horizons.

The Fluorspar Veins

Important development work and prospecting have been carried out on at least two veins, at six different points. Definite correlations of veins at any two mines or prospects have not been established, so that the number of tested veins may be as great as six. The Chinn calcite mine, on the south side of the river just east of Mundy's Landing, may be doubtfully correlated with a vein which outcrops and has been prospected on the north bluff of the river. Four other mines and prospects are situated downstream for a distance of two and a half miles (straight line). It appears from their relative positions that these may be situated on either the Chinn calcite vein (Green Million vein of Miller's paper) or on another of nearly parallel course, roughly between one-quarter and one-half mile west. Lack of continuous exposure between these openings makes it possible that they may, indeed, be situated upon relatively short,

[5] See general treatises and texts on mineral deposits and economic geology. Citations numerous.



(34) Key map of Central Kentucky field. 1. Chinn mine (calcite); 2. Prospect; 3. Moore mine; 4. Prospect; 5. Twin Chimney mine; 6. Dean mine.

closely spaced, and nearly parallel veins. The structural relations of all preclude any definite assurance of continuity. The veins all occupy tension fractures along which there has been practically no relative displacement except minor local displacements in nearly horizontal directions.

Mineralogy of the Veins.

The minerals occurring in the developed veins include:

Calcite
Fluorite.
Barite.
Sphalerite.
Galena.
Marcasite.

Of the non-metallic minerals there is no rule to be stated regarding preponderance. In the Chinn mine calcite is the only mineral present except for an occasional grain of sphalerite; in other mines and prospects calcite fluorite and barite appear in variable relative proportions. In general, except for very local concentrations, barite is clearly minor to the others. At some points it constitutes much of the vein width.

Among the metallic minerals the sphalerite (zinc blende) appears to be the only important sulphide. It was never observed in large amounts in the vein exposures examined and probably has no appreciable economic value even as a by-product of the fluorspar industry. Galena appears to be very rare in the fluorspar veins, though in other mineral veins of the Bluegrass region where fluorite is absent both galena and zinc blende are reported in considerable amounts and indeed attempts have been made to develop primarily for their recovery.

Marcasite, the pale bronze-yellow sulphide of iron, is found in fluorspar throughout the district. It appears as inclusions in the fluorspar, in the shape of very narrow thin leaves chiefly along cracks. It is never present in large amounts and in general is of insufficient quantity to seriously affect the quality of the fluorspar.

Fluorspar.

This mineral is known to occur in two or three veins outside (though not greatly remote from) the producing area which has been called the "fluorspar district." In these cases, however, it is not proven in abundance.

The fluorspar of central Kentucky is colorless or white, coarsely crystalline. In cavities within the veins and walls well-formed cubes, transparent and colorless, are found. Such crystals frequently contain very small marcasite inclusions which, as thin narrow films occupy cleavage spaces and fractures in the fluorspar. Many crystals are free of such inclusions, however, and should be a fruitful source of "optical fluorspar" excellent in quality. The massive vein fluorspar is either translucent white or transparent colorless material of obviously high quality with little included matter that would prevent clean milling. Minerals usually associated with it in the mined product are calcite, barite, and sphalerite. Silica is characteristically very low. The vein fluorspar appears unusually clean. The mineral was not seen without some or all of the associated minerals just mentioned.

Calcite.

This is probably the most abundant mineral of the veins in this section of the Bluegrass. It occurs in very coarsely-crystalline form, and in the fluorspar veins is always white, translucent to opaque, and of rather exceptional purity. Miller [6] reports the transparent variety known as "Iceland Spar" in a recently disclosed vein near Camp Nelson. In the fluorspar veins scalenohedral crystals occur in cavities.

The mineral may constitute the entire vein filling at some places as at the Chinn calcite mine, on the Green Million vein in Mercer County, on the east side of the Mundy's Landing crossing of the Kentucky River. Because of its exceptional purity and whiteness here the mineral has been mined and marketed for use as "Spanish White." This is the only strictly calcite mine known to the writer, though it seems that some of the calcite of other veins in both the western and central fluorspar districts is of sufficient purity and quantity to comprise a by-product providing the market is favorable. At one place

[6] Geology of Kentucky, p. 326.

in the Chinn mine a very small quantity of zinc blende was found in the calcite vein, but fluorspar appears to be entirely absent.

Sphalerite (Zinc Blende).

The zinc blende of the fluorspar veins is a very dark greenish-gray to nearly black variety, and in this respect contrasts sharply with the yellow, brown, and reddish varieties that occur in the western Kentucky veins. It is always minor in amount, though other barytic veins of the Bluegrass, not fluorspar-bearing, are reported to carry considerable amounts.

Barite.

This mineral ranks third in prominence in the fluorspar veins. It is sometimes in coarsely-crystalline, sometimes in finely-crystalline aggregates. Most frequently it appears as comparatively narrow bands roughly parallel to the vein structure, giving the vein exposures a banded or "ribbon" appearance. It is characteristically associated with either fractures within the vein or with the wall contacts, frequently penetrating the vein filling irregularly. Its color is white to creamy-white except where stained a deep yellowish or reddish shade due to the infiltration of iron-bearing surface waters and clay material.

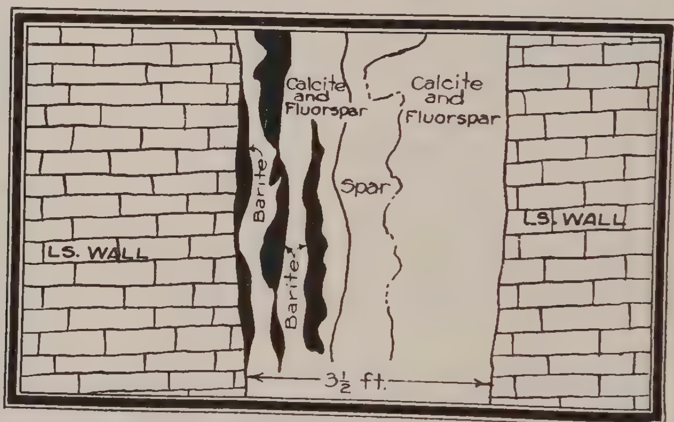
Structure of the Veins.

Without known exception the veins fill simple fissures and are not genetically related in any discovered manner to fault fissures. Almost no vertical displacement of walls can be discerned. At one place, however (Moore mine), both walls showed nearly horizontal slickensides, though not at the same point in the vein. The maximum pitch of the striations observed was about 25° toward the south. The fissures appear to be more definitely of the order of rather extensive joint fractures in the limestone country rock, enlarged, indeed, by the solvent action of ordinary ground waters. The wall rocks are always limestone, and it appears probable that at the horizons of shale formations the fissures, and consequently the vein matter will practically or wholly pinch out.

In all cases seen the veins are vertical in position. Their trends are approximately north-south, varying easterly or westerly by only a few degrees. At the Chinn calcite mine the trend is N 6° E.

The veins are found to split in places inclosing thin wedge-shaped slabs of the wall rock between narrow strips of vein matter.

While vein widths greater than twenty feet have been reported in the Bluegrass region no such width was observed in the accessible openings of the fluorspar veins. A variation from a fraction of an inch to about six feet appears to be a characteristic range, with an abundance of lenses of the order of



(35) A section in roof of drift at Twin Chimney mine.

two to four feet in maximum width of the fluorspar bodies. The veins do not persist with uniform width, but widen and narrow frequently.

Paragenetic Relations of Minerals.

No definite order of deposition for all the minerals has yet been positively established. Much of the barite appears to have been deposited subsequently to the fluorspar, particularly along contacts near the walls and in the more pronounced fissures cutting other vein minerals. Numerous instances may be noted, however, of fluorspar veinlets crossing barite bands. The coarse calcite is, in places, intergrown in a very complex manner with the fluorspar, and at other places it appears in definite bands, though presenting a very irregular contact with the fluorspar.

As a general rule, the contacts between barite and other minerals are quite sharp, while those between calcite and fluorspar are irregular. There is a strong suggestion of the replacement of some of the calcite by fluorspar, but the importance of this mode of deposition is not obviously great, and may be very minor. Undoubtedly much calcite has been deposited since the precipitation of fluorspar in the veins and it is indeed likely that the mineral has seen long continued deposition as compared with the fluorspar.

(36) Section at a face in Moore mine (Faircloth) showing relations of minerals and typical vein structure. F. fluorspar; c. calcite; Ba. barite (black); Ls. limestone walls

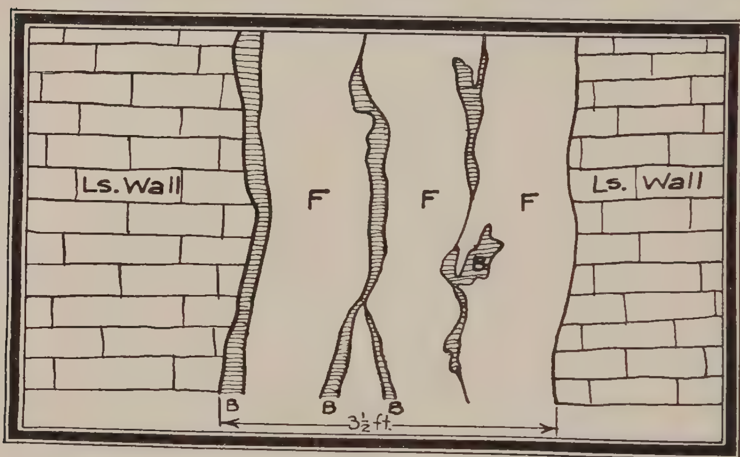
Zinc blende appears only in very small quantity and was probably introduced along fractures together with barite which it most persistently accompanies, subsequently to the deposition of the fluorspar.

The sketches, Figs. 35, 36, 37, show sections of the veins at numerous places.

Origin of the Veins

The mineralogic, geologic, and structural features of the veins are such as to support the idea of deposition largely or entirely from waters of low temperature, possibly of meteoric origin, though scarcely of pronounced artesian circulation. No attempt is made here to establish the origin. The observed facts bearing on the subject appear through the paper, and are briefly commented upon in this section.

Aside from fluorspar there is no mineralogic association that could be considered suggestive of igneous affiliations any more strongly than of non-igneous connections. Concerning fluorspar itself there is, in general, considerable difficulty in assigning large concentrations of this mineral to be possible from ordi-



(37) A vein section in Moore mine showing barite seams in fluorspar. B. barite; F. fluorspar.

nary ground waters traversing limestone areas and gathering their content of calcium fluoride from these country rocks. The question has been briefly considered in an earlier chapter. On the other hand, the total volume of that mineral appears to be very small indeed when compared with the deposits of western Kentucky or with other vein materials of the Bluegrass. It would appear that the fluorspar of these veins was transported from sources other than immediate limestone areas, but the nature of the solutions and the adequate sources are certainly in question. It is a fact, however, that the mineral is quite frequently found in the joint planes of limestones elsewhere, but always as slight incrustations or in pockets, the total amount being very small indeed. For instance, such occurrences are noted in central New York and in Wisconsin.[7]

The complete absence of any known phenomena that can be safely attributed to igneous activity at depth in the district imposes considerable stress on the imagination to postulate such an origin. It could be, of course, that the faulting in the Bluegrass region was a concomitant effect of deep-seated igneous activity, the adjustment of the "crust" having resulted in such breaks, or that the crustal disturbance accompanying the general upbowing along the Cincinnati arch could cause either faulting or faulting with deep-seated igneous adjustment, or that the phenomenon is more directly related to the general Appalachian revolution.

Mines and Prospects

Owing to the inactivity of the industry at the time of the field investigation detailed statements concerning mines cannot be given. No intention is made to judge the relative merits of properties under development. The mines and prospects listed are inclusive of all that appeared to warrant mention for the purposes of this report.

1. *Chinn Calcite Mine* (Mercer County). Formerly operated by the Chinn Mining Company.

This mine has been mentioned in connection with the discussion of calcite as a vein mineral, and since fluorspar does not occur in the vein here it requires no further mention other than a restatement of its possible situation on a vein which may be fluorspar-bearing elsewhere.

2. *Twin Chimney Mine* (Mercer County).

The mine is situated about one mile north from Mundy's Landing on the northwest bank of the Kentucky River, and around the first large bend of the river from this ferry point. Its bearing from the Chinn calcite mine is a few degrees west of north. It was at one time operated by the Chinn Mining

[7] For the Wisconsin occurrence see Bagg, R. M., in Bulletin Geol. Soc. of Am., vol. 29, pp. 393-398.

Drusy films of fluorite are also found in fractures of the limestone at the East Onondaga quarries, near Syracuse N. Y., according to Prof. T. C. Hopkins (verbal communication). It is interesting to note also that several narrow peridotite dikes have been discovered in the vicinity of Syracuse; no genetic connection, is suggested, however.

PHOTO BY W. R. JILLSON

(38) Panorama of Chinn calcite mine near Mundy's Landing in Mercer County.

Company; the present owners are the Heyward Minerals Company, Pittsburgh, Penn., and Nicholasville, Ky. This company was the only active operator at the time of the investigation.

This is one of the two most extensively developed mines of the district. Entry has been made through a 221 foot shaft, the collar of which is about a hundred feet above water level of the river, and by an inclined tunnel opening about half-way between the shaft collar and the river leading to the 96 foot level of the shaft. The vein bears practically north-south. The mine was filled with water below the 96 foot level. This drift has been partly stoped, by the overhand stoping method, the development reaching to a distance of 110 feet along the drift, and for part of the distance to a vertical height of thirty feet (communication).

Vein widths up to 3½ feet were seen, composed of fluorspar, calcite, and barite, in irregular banding. In places a slight breccia of wall rock is cemented by vein matter. Fig. 35 shows a section of the vein on the 96 foot level.

A modern crushing and jigging mill has been constructed on the property for the concentration of the product from the three properties of the company.

3. *Dean Mine* (Mercer County).

This mine is situated in the west bluffs of the river about one mile north of the Twin Chimney mine. It was worked during part of 1920. The vein, up to three feet in width and with the usual variability, is exposed along the face of the cliff which has here a north-south direction. The vein may be a continuation of the Twin Chimney; it has not been continuously traced.

Barite and calcite are associated with the spar. Horizontal slickensides appear in the vein matter and on the walls indicating some subsequent displacement horizontally along the vein. At one place the fluorspar body winds rather irregularly through a wall-rock breccia.

4. *Moore Mine* (Woodford County).

About one-eighth mile north of the ferry at Mundy's Landing and back of the Chinn homestead. Formerly owned by the

Central Pigment Company, now in hands of Heyward Minerals Company.

This mine is developed through two adits, 30 feet apart vertically, extending nearly 600 feet into the river bluff. At the face of the lower and longer adit a 3½ foot vein of fluorspar with some barite was seen. Throughout the workings barite appeared to be localized chiefly along shears and wall contacts. A small amount of calcite is present throughout; in a few places the mineral is very prominent. The vein sections appear banded with the three minerals; the contacts between calcite and fluorspar bands are generally very irregular. (See Figs. 36, 37.)

A maximum vein width of six feet was noted in the lower adit.

Nearly horizontal slickensides appear on both walls; the pitch was toward the south.

The vein course is slightly west of north.

It is possible that the Moore, Twin Chimney, and Dean mines may be on the same vein. The trends are closely similar and the relative positions approximately rectilinear.

Prospects.

Two prospects are to be mentioned, both in Woodford County. The veins cannot be described; their structural and mineralogic features appear to be similar to those previously mentioned.

One of the prospects is north, slightly east, of the Chinn calcite mine, on the opposite bluff, and may possibly be on a continuation of the same vein, though with a change of fluorspar-bearing character, or it may be on a divergent vein.

The second prospect is in the river bluff nearly opposite the Twin Chimney mine, though not on the same vein. It may possibly be a continuation of the vein of the Moore mine though this has not been continuously traced between the two points, being lost in the terranes of the upper limestones.

Very little work appears to have been done at either of these prospects.

Remarks.

In general the veins of this district are comparatively narrow. There is no indication that they may be expected to con-

PHOTO BY W. R. JILLSON

(39) Faircloth's fluorspar mine, Heywood Mineral Co., near Mundy's Landing, Kentucky River, in Woodford County.

tinue to any great depth, possibly being limited by the High Bridge limestone series. Evidence that there may be a considerable widening of the veins at greater depths than are now worked is also lacking. However, the lack of reasonable certainty as to the exact mode of origin of the veins makes a definite statement regarding these features impossible and the matter remains speculative.

The fluorspar is of unusual high grade and the carefully milled product, free of the very objectionable barite and zinc blende, should enjoy a sustained market so long as the material can be profitably mined. It is to be expected that production from this field will increase somewhat; though not to become a serious competitor with the western field on a quantitative basis, the purity of the milled product and the closer proximity to principal consuming points should react strongly in its favor.

CHAPTER X.

ECONOMIC CONSIDERATIONS

Uses

Fluorspar possesses a wide variety of uses, chiefly in the metallurgical and ceramic industries, but also in certain other chemical applications which may sometime draw quite heavily upon the resources. Its industrial value lies, of course, in the high content of the very active element fluorine. Relatively few members of the mineral kingdom contain this element in large proportions though numerous minerals carry a determinable amount. Of all fluorine-bearing minerals there is in fact but one other that is found in sufficient concentration, and in which there is a high enough percentage of fluorine to give it economic value, i. e., cryolite. Cryolite is mined only in Greenland, is imported in small quantity (as compared with the yearly consumption of fluorspar), and the production appears to be almost entirely absorbed by a certain specific industry. Moreover, cryolite is not adapted to most of the uses to which fluorspar is put, and is not to be considered a competitor.

Steel Industry.

The chief use of fluorspar is in the manufacture of basic open-hearth steel, in which process it is added as a flux to the furnace charge. Its specific purpose herein is to give the basic slag a higher degree of fluidity without necessitating the attainment of a higher temperature, and at the same time to facilitate the removal of objectionable and very refractory substances, particularly sulphur and phosphorus. The quantity used is always a very small proportion of the total furnace charge, never more than twenty pounds per ton of steel produced. The usual practice is reported by one company as varying from four to seventeen pounds per ton of steel, with an average of about eight pounds.[1]

Thus the mineral usually constitutes much less than one-half of one per cent of the charge. However, the annual basic

[1] See Illinois State Geological Survey, Bulletin 41.

open-hearth steel production constitutes from 75 to 80 per cent of the total steel production of the country, and in 1920 amounted to 31,375,723 gross tons.[2] On the basis of eight pounds of fluorspar per ton of steel this would require approximately 125,000 tons of the mineral to satisfy the requirements of the steel industry alone. For this use the fluorspar should be low in silica, sulphide, and sulphate mineral impurities. The action of silica is to combine with some of the fluorite thus reducing the amount available for other constituents of the charge, while the sulphur-bearing minerals introduce this undesirable element into the finished steel. These impurities are common in both domestic and imported fluorspar, the silica occurring either as quartz within the vein-matter or as included fragments of silicious wall-rock material, the sulphides and barium sulphate as vein accessories. (For a discussion of the mineral associations in the Kentucky veins see Chapter V.) Calcium carbonate, as limestone or as the mineral calcite, is a basic fluxing material and is therefore not objectionable in the charge, but rather serves to dilute the quality of the fluorspar, on which account it must be kept within certain specified limits if the fluorspar is to bring standard market prices.

Commercial grades of "fluxing spar" are generally guaranteed to contain less than 6% silica and at least 85% calcium fluoride. Lower grade material may find some market at prices below those of guaranteed standards if the excess impurity is chiefly calcium carbonate. The grade known as 85-5 contains 85% or more of calcium fluoride and 5% or less of silica. This is the chief standard grade of fluorspar for fluxing. The material is sold in two forms, known as "lump" and "gravel." Much fluorspar of higher grade has been marketed for fluxing purposes. Such material is that which carries silica values less than 5% and greater than 2%, with a calcium fluoride content of more than 90%; quite commonly, however, high grade material of this nature which just fails to reach the high standard imposed for "acid spar" is mixed with material of low grade to bring the latter up to standard. If such high grade spar

[2] U. S. Geological Survey; Mineral Resources of the United States, 1920, part one, page 396.

is sold directly, however, without mixing, it should bring the producer a correspondingly higher market price.

Ceramic Industries.

The ceramic industries use high grade fluorspar in the manufacture of enamels for coating metalware. In this direction a considerable quantity of the mineral finds a market that bids fair to increase. In the glass manufacturing industries fluorspar is added to the glass-pots for producing opalescent and translucent glasses. For ceramic purposes cryolite has been used for some of the uses to which fluorspar is adapted, but the restricted production of the former makes its substitution for fluorspar improbable. It is to be expected that the increase in ceramic products will cause some increase in the use of fluorspar, since there is no present substitute that will take the place of fluorine compounds in the enamel and glass melts.

The fluorspar for these uses must be of much higher grade than that of possible use in the fluxing operations of the metallurgical industries, and the market quotations are made chiefly on a stricter silica and metallic basis. While silica is not detrimental to the ceramic and glass mixtures, which are highly silicious, the substance reacts with calcium fluoride, thus reducing the available fluoride in the melt. The chief objectionable impurities are the minerals containing lead, iron, copper, and zinc, inasmuch as very small quantities of these elements strongly color the glass or enamel. Lead sulphide (as galena) is the chief objectionable metallic mineral in Kentucky spar; iron and copper sulphide are rarely present in appreciable amounts. Fortunately, galena may be very easily detected and removed by careful milling so that some Kentucky producers put a milled fluorspar on the market which is adapted to ceramic uses. Zinc sulphide is also objectionable. While only a minor proportion of the spar mined in Kentucky may be sold in this direction, due largely to excessive silica content, it is probable that material of this quality may be prepared by careful milling of the product from numerous deposits which now market the lower grades.

Chemical Industry.

Fluorspar constitutes the basic material for the manufacture of hydrofluoric acid, widely used in chemical industries where solvent of silica or silicious material is required. The fluorspar for this use must be of highest grade, carrying 98% or more calcium fluoride, and 1% or less silica, to meet standard specifications. Spar carrying 97% calcium fluoride, and silica slightly in excess of 1% may frequently be sold in this direction at a reduced rate. It appears probable that the 98-1 requirement wlll be increasingly difficult to meet owing to exhaustion of "acid" fluorspar bodies, which are more limited and localized in their occurrence than other grades. By very careful milling the production of the quality spar may be increased except probably from veins where zinc sulphide is a prominent constituent. As pointed out in an earlier chapter numerous microscopic examinations of zinc bearing specimens discovered a stronger introduction of minute quartz crystal with zinc sulphide than with lead. Both permeate the fluorspar; removal of the zinc blende by milling will not entirely remove the silica.

Minor industrial uses of fluorspar may be listed as follows:

(1) As a flux in the smelting of silver, lead, copper, and gold ores (not universal practice).
(2) As a flux in the refining of metals (not universal practice).
(3) As a flux in foundry metallurgical operations.
(4) As a re-agent in the extraction of aluminum from bauxite.
(5) As a bond for emery wheels and carbon electrodes.
(6) In the manufacture of Portland cement.
(7) In the manufacture of sodium fluoride as a wood preservative.
(8) Experimentally in the extraction of potash from silicate minerals, such as feldspar.
(9) In the manufacture of glazed bricks and vitrolite.
(10) In the extraction of potash from flue-dust.

Several of these uses may open a considerable future need for fluorspar, depending, of course, upon the success attending the processes involved.

Optical Fluorite.

Particular scientific value is attached to transparent pieces of fluorspar, which are also flawless and colorless, or nearly colorless. From such material apochromatic lenses are ground to be used in the lens systems of high grade and research microscopes. This adaptation of fluorspar is due to the following characteristies: the index of refraction is low, the mineral is isotropic, and its dispersion is lower than that of other lens materials. To this last property its value is especially due, though the isotropic character is also essential. Fluorspar is always entirely isotropic except when it has been strained by high shearing or torsional stresses. The anisotropism produced by straining is always low, but may be sufficient to prevent a crystal, otherwise favorable, from being used for optical purposes. The property is tested by means of polarized light in special laboratories, and may not be tested for in the field without the use of costly apparatus.

Colorless material is preferred by lens manufacturers, but colored material may be used acceptably, providing the color consists of a light tint, and is uniformly distributed.

Lenses are ground in several sizes, the smallest being about one-fourth inch in diameter. The value attached to any material depends partly, therefore, upon the size of lens which may be obtained from it; the value is not always in direct proportion to the size of lens obtainable, however, since material suitable for the large lens is much more difficult to obtain. The mineral constituting the finished lens must be entirely free from flaws, fractures, and cleavage cracks. Large pieces of crude fluorspar show innumerable fractures, but occasionally crystals or lumps are found from which certain portions that would be suitable for lens manufacture could be removed by careful manipulation. Indeed, it is usual that only a very small proportion, probably less than 5% on the average, of the material sold as optical fluorite goes into lens manufacture, so great is the waste that results in selection and grinding.

Large crystals frequently provide material of optical quality. On the other hand, quite ordinary-looking lumps of white spar, often, when broken open, reveal a flawless core; according to one investigator connected with a prominent optical goods concern such lumps have been a most fruitful source of lens material.

Owing to the softness of the mineral, and to its ease of fracture, crude optical fluorspar should be handled and packed with extreme care.

The quantity of material used for optical purposes cannot be stated. It is, of course, small; a few hundred pounds will probably supply the yearly requirements. Prices are variable according to quality and usually sold on the pound basis, from $1 to $20 a pound. Particularly fine specimens have individual value and should be so marketed. There is no definite market price, however, and producers must adjust their quotations with the consumers on the individual merits of their products.[3]

Fluorspar Producing Districts.

While fluorspar is a common constituent of certain metallic veins and is of world-wide distribution, in comparatively few instances is the mineral sufficiently concentrated or pure enough to allow its economic recovery, even as a by-product. From year to year new deposits are being discovered from which, if necessary, the mineral could be obtained for the market, but in most cases remoteness and the character of the deposits appear to weigh prohibitively against them as factors in competitive production.

Domestic Sources.

Besides Kentucky and Illinois, states which have reported a market for fluorspar production to the United States Geological Survey since 1918, include: Arizona, Colorado, New Hampshire, New Mexico, Nevada, Utah and Washington. In Colorado and New Hampshire only has a sustained (but small) production been reported.

Colorado.

Fluorspar is produced from two localities, (1) Wagon Wheel Gap, Mineral County, and (2) Jamestown. The peak of production since 1913 was in 1918, when 38,475 tons were reported as marketed. In 1921 marketed production was 3,143 tons. Colorado is an appreciable factor in the industry, but the production has been, and will probably continue to be taken care of mostly by western consumers.

[3] For more complete information regarding "optical" fluorite see (a) J. E. Pogue; Optical Fluorite in Southern Illinois, Illinois Geological Survey, Extract from Bulletin 38, 1918; and (b) E. F. Burchard, Fluorspar and Cryolite in 1917, U. S. G. S. Mineral Resources of the United States, and (c) E. F. Burchard, Our Mineral Supplies, U. S. G. S. Bulletin 666-CC, 1917.

Arizona.

The production for this state appears so far to have been negligible, and to have come as a by-product in the concentration of other ores. There is no indication that this state will be a serious competitor, due to lack of known large deposits and to remoteness from the eastern consumers.

New Hampshire.

The production from this state, though sustained, is very small. The only deposit reported is in Cheshire County. Although in fairly close proximity to the chief fluorspar markets, the very small amount mined is negligible in comparison with the production in the Kentucky and Illinois districts.

Nevada.

Small productions have recently been reported from a mine near Beatty, Nevada, according to the statistics of the United States Geological Survey.

New Mexico.

Mines in this state have produced and marketed fluorspar since 1918, at which time activity was stimulated by the temporary high prices. The maximum reported by the United States Geological Survey is 6,350 tons, produced during 1920. It is not yet possible to predict future importance of the deposits, but their remoteness from eastern markets militates against their developing into strong competitors with the eastern fields.

Utah.

A very small production has been reported since 1918. V. C. Heikes has described the single commercial deposit.[4]

Some interesting similarities with the Kentucky veins are brought out. The mineral occurs in veins cutting Pennsylvanian limestones, and is associated with calcite, silver, copper, lead, barite, and quartz. The deposits are described as "replacement veins in limestone." Workable widths of 15 feet are reported. The fissures carrying the mineral have slight displacements, and the country rocks are cut by basaltic dikes. The possible future development for these veins is not predicted.

[4] U. S. Geological Survey, Mineral Resources of the United States, part 11, 1921.

Like other western fields, however, any future moderately large production can be taken care of by western consumers.

Foreign Sources.

Fluorspar has been imported from England, Canada, and Germany. Importation from England has been of long standing, and in some years has undoubtedly had very sensible effect upon the American market. The material has frequently been carried as ballast cargo, and as such been a successful competitor of American spar in the easternmost markets.

Germany has exported small quantities of fluorspar to this country, but the amount seems never to have been large. Of late years, production has been stimulated in Canada; Ontario, where the advantages of a fairly near market are felt, has shown a fairly large production since 1915. Until 1920, this province was the greater producer, but in 1920 it was surpassed by British Columbia, when a production was reported nearly twice that of Ontario.[5]

Total Canadian production in 1920 was 11,235 tons. The Madoc Ontario district is described in the 1920 Summary Report of the Geological Survey. The Madoc veins appear to be numerous within an area about eight miles long and five miles wide. Barite is said to be a prominent constituent, while metallic sulphides are rare. Calcite accompanies the fluorspar. The origin of the deposits is in doubt, so that nothing can be predicted as to probable depths to which the fault fissure veins extend. The deposits have the advantage of being near the eastern consumers, it being only about 25 miles from the Canadian shore of Lake Ontario, and being reached by a railroad branch line.

Deposits of Great Britain.

A summary report on Fluorspar in Great Britain, issued by the Geological Survey of Great Britain in 1916, has been abstracted by E. F. Burchard.[6]

The deposits of Great Britain occur in four districts, but only two are said to be economically important. These two

[5] Canada: Dept. of Mines, Mines Branch; Annual Report on the Mineral Production of Canada during the calendar year 1920. Ottawa: 1921.

[6] Mineral Resources of the United States 1916, part 2, United States Geological Survey, Washington, D. C., 1917.

districts are (1) Derbyshire, and (2) North of England (Durham). Because of their interesting similarities with Kentucky deposits and also because of the economic activity of English fluorspar in American markets, a brief summary is here presented.

Durham.

The fluorspar bodies of this district occur as veins and "flats" in gently dipping limestones, shales, and sandstones of Paleozic age. Limestones appear to be the most favorable strata, but the fluorspar bodies are said to be common also in sandstones. The veins occupy simple fractures and normal fault fissures, sometimes extending horizontally into limestone walls. The mineral association is quartz (most common accessory), galena, calcite (never abundant). Barite is absent. At the time of the report the vein had been opened to a depth of nearly 400 feet, and with no apparent diminution in quality. Regarding the reserves the statement is made that ". . . the number of still untouched veins and the relatively small amount of work done on the others create a strong impression that the industry is still in its infancy and that the present output could be greatly increased without danger of exhaustion for a prolonged period of years."

"Most of the spar is exported to America and Russia for steel smelting."

Derbyshire.

In this district the deposits occupy vein fissures and cavities in Carboniferous limestones, which have an exposed thickness of 1700 feet. Besides simple vein structures are also found tabular horizontal, or "bedding" deposits. The fluorspar is said to be chiefly confined, however, to the uppermost 300 to 400 feet of limestone, the overlying sandstones and shales being barren.

Igneous rocks as sheets penetrate the upper part of the limestone. The fluorspar is here associated with barite, calcite, galena, and somctimes zinc blende (sphalerite). Quartz and copper minerals are rare.

"The available supply of fluorspar is regarded . . . as almost intact and capable of bearing the strain of a greatly increased output for a great number of years. It must be added, however, that the surface waste heaps which have been the mainstay of the Derbyshire output for the last six years have now been well picked over and are no longer of serious account for future supplies.''

Domestic vs. Foreign Fluorspar.

Fluorspar has been imported from Great Britain in large part as ballast, making possible a lower market price than would be the case were the material exported from that country as a primary cargo. Also, American consumers favor the domestic fluorspar from Kentucky and Illinois because of its higher average quality. The following statements by certain eastern consumers appearing in a government report[7] are of interest in this connection.

''According to a consumer in the Lehigh Valley who uses a large quantity of fluorspar imported from England, the foreign spar purchased in 1919 averaged 75% of calcium fluoride and 4% of silica and its cost delivered at the works was about $18 per ton, compared with a cost of about $25 a ton for domestic spar which averaged 85% calcium fluoride and 6% silica. This consumer states that the better grades of domestic fluorspar are more efficient than the imported spar; that some of the foreign material, especially that received during the war, and some grades of domestic material were unsatisfactory; and that on a fairly even price basis the better grades of domestic fluorspar are to be preferred.''

A consumer in southeastern Pennsylvania states that the material imported in 1919 averaged 83% to 87% of calcium fluoride, and 8% to 10% of silica and that it cost delivered to his steel plant about $21 a ton or about 25c per unit of calcium fluoride.

The following statement is also made concerning the cost of imported material in 1921:[8]

''According to the values reported, including a duty of $1.34 a short ton ($1.50 a long ton), but excluding the ocean

[7] Mineral Resources of the United States, 1919, part 2, page 356; Hubert W. Davis on Fluorspar and Cryolite in 1919.

[8] Mineral Resources of the United States, 1921, part 2, page 45; U. S. Geological Survey, Washington, D. C.; H. W. Davis on Fluorspar and Cryolite in 1921.

freight charge, the average cost of imported English fluorspar to the consumer was $8.66 a ton in 1921, compared with $16.11 for domestic merchantable gravel at the mine or mill."

It would appear that on an even basis of calculation domestic fluorspar is preferred, so that a moderate protective tariff, probably not exceeding $6.00 or $7.00 per ton, would insure competition on quality merits and sufficiently protect the domestic operator.

Production and Imports.

The statistics involved in the treatment of this topic have been obtained from the following sources:

(1) U. S. Geological Survey, Mineral Resources bulletins of several years.

(2) The Mineral Industry, McGraw-Hill Publishing Company, several years.

(3) Kentucky Geological Survey, Series 6, Vol. II, Production of Fluorspar in Western Kentucky by W. R. Jillson, in Economic Papers on Kentucky Geology.

(4) Canada, Department of Mines, Mines Branch, Annual Report of the Mineral Production of Canada, 1920.

The following table gives the approximate fluorspar production by countries for the year preceding the World War (1913):

	Metric Tons
United States	104,853
Canada	....
Great Britain	54,522
Austria-Hungary	20,000*
Germany	8,000*
France	7,524

* No definite statistics; figures estimated.

The Great Britain production has in large part been derived from the waste piles of Derbyshire mines, according to the special report of the Great Britain Geological Survey (1916), but this source is reported to be nearly exhausted, so that the future supply must be obtained by mining operations in the Derbyshire and Durham districts.

United States Production.

The domestic production of fluorspar since 1885 is shown in the following table,[9] which indicates the growth and importance of the industry:

Year	Production (short ton)	Value
1885	5,000	$22,500
1890	8,250	55,328
1895	4,000	24,000
1900	18,450	94,500
1905	57,385	362,988
1910	69,427	430,196
1915	136,941	764,475
1920	186,778	4,718,547

These figures represent the annual production for the years designated, and while the table does not show the periods of rise and decline, it does indicate the rapid upward trend. The fluctuation in production since 1901 is indicated by the following table.

Total production (all grades included) by states, for the years 1902 to 1921, has been compiled from various sources, and appears in the following table:

	Kentucky	Illinois	Colorado	New Mexico	All Others	Total, U. S.
1902	29,030	18,360				48,018
1903	30,835	11,413				42,523
1904	19,096	17,205				36,452
1905	22,694	33,275				57,385
1906	11,793	28,268				40,796
1907	21,058	25,128				49,486
1908	6,323	31,727				38,785
1909	7,800	41,852				50,742
1910	17,003	47,302				69,427
1911	12,403	68,817				87,048
1912	10,473	103,937				116,545
1913	19,622	85,854	a	a	10,104	115,580
1914	19,077	73,811	a	a	2,228	95,116
1915	19,219	116,340	a	a	1,382	136,941
1916	19,698	126,369	a	a	9,668	155,735
1917	43,639	156,676	17,104	a	1,409	218,828
1918	87,604	132,798	38,475	3,437	1,503	263,817
1919	32,386	92,729	9,687	2,346	1,142	138,290
1920	46,091	120,299	12,852	6,355	1,183	186,778
1921	15,266	12,477	3,143	3,507	567	34,960

Of particular interest in this table are (a) the maximum periods of 1912 and 1918, and (b) the minimum period of 1921.

[9] Data edited from U. S. Geol. Survey, Mineral Resources of the U. S.; 1916, part 2, page 313; 1921, part 2, page 43.

In 1921 the production fell below that of any year since 1901 due, in part, to the general industrial decline and, in part, to the fact that both the consumers and producers had accumulated large stocks during 1920 and 1921. The low production level reached in 1921, therefore, does not indicate a lack of need for the mineral. Despite the enormous drop in production the average price per ton for the peak year (1918) was practically the same as for the lean year (1921).

Imports.

Importation from England amounted to 17,096 short tons in 1920, the maximum since 1913. In 1921, the importation from this source was only 1,644 tons. In the same years, importation from Canada decreased from 7,068 tons in 1920 to 4,370 tons in 1921. Imports from other countries were negligible.

Canadian Production.

The Department of Mines, Canada, gives the following statistics of production for the years indicated:

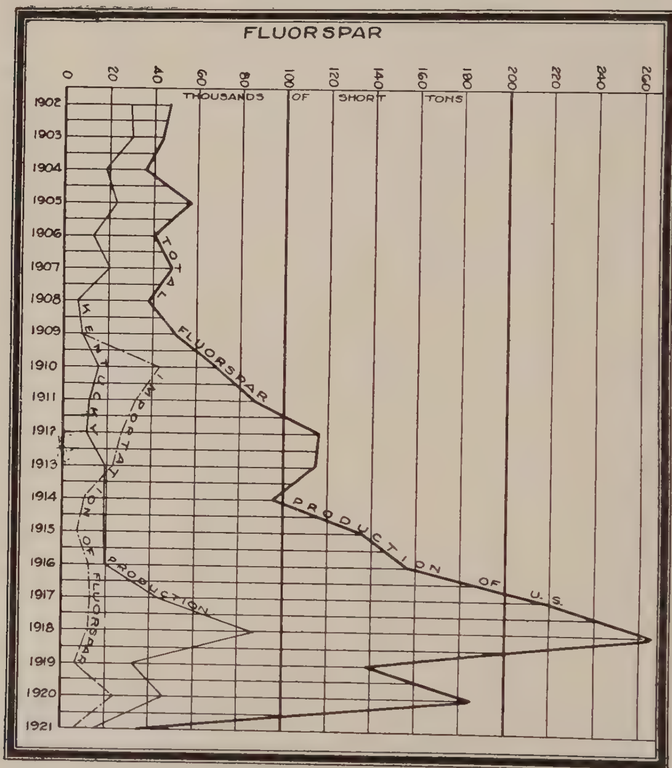
Year	Ontario	British Columbia
1917	4,249	......
1918	7,187	175
1919	3,425	1,638
1920	3,758	7,477

Kentucky Position in Past Production.

Fig. 40 is a graphical representation of the table on page 180 emphasizing the relation of the Kentucky fluorspar production, as indicated by statistical data of the United States Geological Survey. No data are available for production in the central Kentucky district so that the Kentucky statistics in all cases show combined production for the two fields. The curve of importation is added to this figure.

Market Prices.

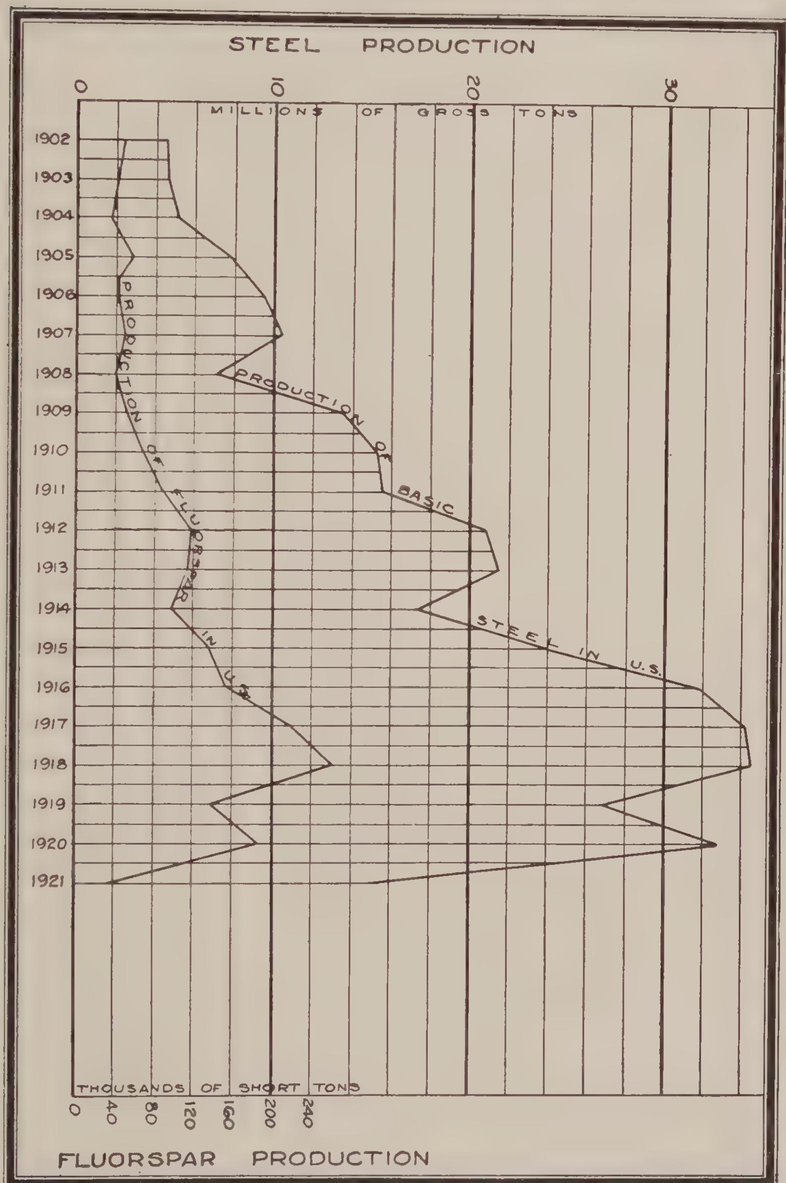
From an average (all grades), of $5.80 per ton for the year 1913, the market price rose to a maximum of $27.27 in the Kentucky field in 1919, and declined therefrom to $19.29 in 1921. These quotations are undoubtedly slightly higher than the averages for the fluxing grades, which make up the great bulk of fluorspar production. For 1920, about 6% of the mined product went to the glass and enamel trade, for which an average price of about $44 per ton was obtained, while 10% was of acid quality selling at an average price of approximately $37. Thus the



(40) Production and importation curves showing relation of Kentucky fluorspar production to total U. S. production and to imports. Imports mostly from England.

fluorspar production is mostly taken up in the fluxing grades and, at present at least, fluctuations in the steel industry mostly control the fluctuations in domestic fluorspar production.

The graph, Fig. 41, shows the relation of fluorspar production to that of the basic open-hearth steel through a period of seventeen years.



(41) Graphical representation of data for United States production of fluorspar and basic steel.

The market prices, as of December 16, 1922, are given below.[10] This table indicates the standard grades:

Fluxing gravel, 85% CaF_2, not over 5% SiO_2, $21.50 f. o. b. mines.
Fluxing gravel, 85% CaF_2, not over 6% SiO_2, $21.00 f. o. b. mines.
Fluxing gravel, 80% CaF_2, not over 5% SiO_2, 20.00 f. o. b. mines.
Ground acid grade, $45.00 in bulk.
Ground enameling grade, $35.00.
No. 1 lump, $30.00, f. o. b. Illinois mines.
No. 2 lump, $25.00, f. o. b. Illinois mines.

It is reported that during the years 1917 and 1918 a very large proportion of the market fluorspar was sold on old contracts at prices very much under the prevailing market prices so that the "average prices" given for those years (1917-1918) are undoubtedly lower than actual prices occasioned by trade demands of those years. In such cases old contracts called for "spar" at prices between $5 and $10.

It appears certain that with increasing demands and increasing mining costs the market prices cannot be expected to drop in the future to or near the pre-war level. It is doubtful, indeed, if fluxing spar will ever drop below $12 per ton; in periods of demand it will probably be maintained at $15 to $20 per ton. Acid spar must continue to bring relatively very high prices owing to its scarcity and the cost of milling to acid quality.

[10] From Engineering and Mining Journal-Press of that date. This journal publishes the prevailing market prices each week.

APPENDIX

Companies and individual operators of the Western Kentucky Field. This list includes certain companies of past importance not now holding important mineral rights or lands. Numerous minor prospects have been omitted.

Name.	Field Address.	Home Office.	Mines and Prospects.
American Fluorspar Co.	Salem, Ky.	Wheeling, W. Va.	Hudson. Lovelace.
Aluminum Ore Co.	Mexico, Ky.	East St. Louis, Ill.	Haffaw. Memphis. Klondike.
Arnold and Bellemy (See Claylick Fluorspar Co.).			
Ben Mac Mining Co.	(Holding of Kentucky Fluorspar Co.)		
Blue and Nunn.	Marion, Ky.		(Zinc carbonate, abandoned). Old Jim. Little Jim. Nine Acres.
Blue Grass Mining Co. (Holding of Roberts Fluorspar Co.)			
Central Spar Mining Co. (Leased to Haynes and Guess).			Gill.
Crystal Fluorspar Co.	Marion, Ky.		Perrigen Springs.
Claylick Fluorspar Co.	Marion, Ky.		Redd. Davenport.
Clement Heirs.	Marion, Ky.		Clement. (Not in operation.)
Commodore Fluorspar Co.			Reiter. (Holding of Ky. Fluorspar Co.)

Name.	Field Address.	Home Office.	Mines and Prospects.
Commodore Mining Co.	Louisville.		Commodore. (Leased to Haynes and Clark.)
Conyer and Settles.	Marion.		Prospect.
Crosson Cave Mining Co.	Marion.		Crosson Cave.
Cox, F. G.	Marion.		Larue Mine. (Not in operation.)
Davis Mining Co.	Hopkinsville		Matthews.
Denny, O. S.	Marion.		Eva Tanguay. (Not in operation.)
Dixie Mining Co. (absorbed by Ky. Fluorspar Co.).			
Eagle Fluorspar Co.	Salem.		Liberty Bond. Cullen.
Eclipse Mining Co.		Louisville, Ky.	Commodore. (Lease expired.)
Fairview Fluorspar and Lead Co.	Marion.	Fairview, Ill.	Franklin.
Farris and Shumwell.		Paducah, Ky.	Bateman. (Barite.) (Abandoned.)
Farris Fluorspar Co.		Paducah, Ky.	Woods. Porter. (Abandoned.)
Federal Spar Co. (out of existence).			
Gugenheim Mining Co.	Marion.		Lucile.
Giant Fluorspar Co. (inactive).	Marion.		Prospect abandoned.
Haynes and Clark, Haynes and Guess, C. W. Haynes.	Marion.		Lessees of Commodore. Eclipse. Gill. Klondike. Memphis. Reiter. Butler.

Name.	Field Address.	Home Office.	Mines and Prospects.
Hallowell P. O. (?)	Princeton.		Tyrie prospects. (Abandoned.)
Hill, D. B.		Hopkinsville	Edwards. (Not in operation.)
Holly Ore and Mining Co.	Marion.		Holly. Jones.
Kentucky Fluorspar Co.	Marion.		Mary Belle. Susie Beeler. Ada Florence. Beard. Union. White. Pogue. Yandell. Wheatcroft. Brown. Corn (?) Leander White Tabb.
Keystone Fluorspar Co.	Mexico.	Hopkinsville.	Blue and Marble.
K. K. Mining Co.	Marion.		K-K. (Leased to U. S. Fluorspar Co.)
Krausse, E. B.			Columbia. (Abandoned.)
LaGrange Mining Co.	Marion.		Ebbie Hodge. (Under lease.) (Expired 1921)
Mathew Addy Co. (assignees).		Chicago, Ill.	Eaton. Keystone. (by assignment) from Standard Spar Mining Co.
Mitchell, W. P.	Marion.		Mitchell prospect.
Myers and Crider.	Mexico.		Hodge. (By lease.) Nancy Hanks. (By lease.)

Name.	Field Address.	Home Office.	Mines and Prospects.
North American Lead and Fluorspar Corp.	Smithland.		Klondike, S. W. of Salem. Royal. (Not in operation.)
Pasco Mining Co.	Marion.		Part lease on K. K. mine.
Phelps and Hazelip.		Paducah, Ky.	John Hodge Mine, (leased to Myers and Crider).
Pope Mining Co.	Salem	Louisville, Ky.	Two Brothers (also known as Watson) Two Bachelors (also known as Babb)
Rawn, E. V.		Hopkinsville, Ky.	Marble (inactive)
Reed, A. H.	Marion		Big Four Deer Creek
Riley and Larue.	Salem		Riley
Roberts Fluorspar Co.	Marion		Asbridge Tabor
Rosiclare Lead and Fluorspar Co.		Rosiclare, Ill.	Pygmy (abandoned)
Senator Mining Co. (now out of existence).	Princeton		Senator (abandoned)
Southern Mineral Co. (absorbed by Kentucky Fluorspar Co.)	Princeton, Ky.		
Standard Spar Mining Co. of North America (Bankrupt) (See Mathew Addy Co.)			Keystone Eaton
Stribling, E. G.	Marion.		Red Fox. (Hardin.)
Tennessee Mining Co. (inactive)		Nashville, Tenn.	Ben Bolt. (Abandoned.)
Union Mining Co.		Louisville, Ky.	Prospect, Princeton District; abandoned.

Name.	Field Address.	Home Office.	Mines and Prospects.
United Mining Co.	Lola.	Canton, Ohio.	Bonanza. Nancy Hanks.
United States Fluorspar Co.	Marion.		K-K; under lease.
Warren Mining Co.	Marion.	Paducah, Ky.	Fred Brown. Macer. (Hayward.)
West Ky. Ore Co. (absorbed by Kentucky Fluorspar Co.)			
White Fluorspar Co. (inactive)			Glendale.
Zinc Spar Mining Co. (inactive)			Ebbie Hodge.

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